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WAQUOIT BAY WATERSHED

Ecological Risk Assessment Planning and Problem Formulation

RISK ASSESSMENT FORUM
U. S. ENVIRONMENTAL PROTECTION AGENCY
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TECHNICAL PANEL CHAIR:

Suzanne Marcy, U.S. EPA, Office of Research and Development, Washington, D.C.

TEAM CO-CHAIRS:

Maggie Geist, Waquoit Bay National Estuarine Research Reserve, Waquoit, Massachusetts
Patti Tyler, U.S. Environmental Protection Agency Region I, Lexington, Massachusetts

TEAM MEMBERS:

David Dow, National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, Massachusetts

Jeroen Gerritsen, Tetra Tech, Inc., Owings Mills, Maryland

Chuck Spooner, U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Conchi Rodriguez, U.S. Environmental Protection Agency, Office of Prevention, Pesticides and Toxic Substances, Washington, D.C.

Vicki Atwell, U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

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The Waquoit Bay Watershed

Waquoit Bay is a small estuary on the south coast of Cape Cod, Massachusetts, prized by residents and visitors for its aesthetic beauty and recreational opportunities. The watershed covers more than 53 square kilometers (about 21 square miles) of freshwater streams and ponds, salt ponds and marshes, pine and oak forest, barrier beaches, and open estuarine waters. It provides a home, spawning ground, and nursery for plant and animal life including piping plovers, least terns (endangered birds), the sandplain gerardia (an endangered plant), and alewife, winter flounder, blue crab, scallops and clams, and anadromous and catadromous fish.

The history of Waquoit Bay illustrates this trend and the struggle between traditional economic growth and conservation of natural resources. Initially valued for hunting, farming, and fishing, Waquoit Bay now primarily provides aesthetic and recreational opportunities (WBNERR, 1989), demands that have generated residential development and business for local marine-dependent industries.

The environmental problems facing Waquoit Bay include eutrophication, habitat loss, and resource depletion (WBNERR, 1989). Eelgrass that provides life to many animals in the bay is being replaced by thick mats of macroalgae, resulting in fish kills and the loss of bay scallops. The underlying aquifer, which provides local communities their sole source of drinking water, is contaminated by plumes from a Superfund site. Land development is changing the landscape and contributing nutrients and contaminants to the bay. Several research projects and management activities are under way to examine the problems in the watershed and to provide protection for threatened and endangered aquatic and terrestrial species and habitats, to reduce or eliminate pollution, and to restore damaged spawning and nursery sites in the watershed.

The Waquoit Bay watershed was selected as one of the EPA-sponsored ecological risk assessment case studies because of interest by local, state, and federal organizations in the watershed, the type of watershed (estuarine), the diversity of stressors (e.g., nutrients, sediments, obstructions, ground water contamination), a substantial existing database, and willingness by the Waquoit Bay National Estuarine Research Reserve (WBNERR) and EPA Region I to lead the risk assessment team.

Management Goals

The team charged with designing a risk assessment for the Waquoit was comprised of an interdisciplinary and interagency team of scientists and managers who began work in 1993. The management goal was developed through a multistep planning process initiated and completed by the Team: a public meeting to initiate the process, evaluation of goals by interested organizations in the watershed, and a meeting of members of these organizations to review and approve the management goal and Team-derived objectives. The overarching goal developed for the Waquoit Bay watershed risk assessment is:

Reestablish and maintain water quality and habitat conditions in Waquoit Bay and associated wetlands, freshwater rivers, and ponds to (1) support diverse, self-sustaining commercial, recreational, and native fish and shellfish populations and (2) reverse ongoing degradation of ecological resources in the watershed.

The goal was interpreted as 10 management objectives believed to be required to achieve the goal:

- Reduce or eliminate hypoxic or anoxic events
- Prevent toxic levels of contamination in water, sediments, and biota
- Restore and maintain self-sustaining native fish populations and their habitat
- Reestablish viable eelgrass beds and associated aquatic communities in the bay
- Reestablish a self-sustaining scallop population in the bay that can support a viable sport fishery
- Protect shellfish beds from bacterial contamination that results in closures
- Reduce or eliminate nuisance macroalgal growth
- Prevent eutrophication of rivers and ponds
- Maintain diversity of native biotic communities
- Maintain diversity of water-dependent wildlife

These objectives were intended to state explicitly what kinds of management results were implied in the general goal statement.

Assessment Endpoints

Eight assessment endpoints were selected to represent estuarine and freshwater components of the ecosystem, and ecological and human health concerns:

- Estuarine eelgrass habitat abundance and distribution
- Resident and juvenile nursery estuarine finfish species diversity and abundance
- Clam and other benthic invertebrate diversity, abundance, and distribution
- Migratory (sea run) brook trout and alewife herring reproduction
- Freshwater stream benthic invertebrate diversity and abundance
- Freshwater pond trophic status
- Water-dependent wildlife species feeding and nesting habitat
- Bacterial and contaminant content of fish and shellfish

The assessment endpoints are measurable attributes of valued resources identified in the management goals, and the first six represent ecologically important components of the ecosystems.

The include both an entity (e.g., eelgrass) and a measurable attribute (e.g. distribution), and they provide direction for the assessment and are the basis for the development of questions, predictions, models, and analyses.

Conceptual Model

The conceptual models developed for the Waquoit Bay watershed represent a series of risk hypotheses about the relationships between particular stressors and ecological effects expected to be observed in each assessment endpoint (Figure 2). The general watershed conceptual model is a broad representation of relationships among human activities in the watershed (sources), the stressors believed to occur as a result of those sources, and ecological effects likely to occur in each of the assessment endpoints.

Eelgrass is highly susceptible to water quality conditions and requires clear waters with ample light penetration for photosynthesis. Shading by algae and sediments directly impacts eelgrass growth. Excessive growth of macroalgal mats has displaced eelgrass in Waquoit Bay.

Finfish are susceptible to hypoxic and anoxic conditions and toxic contaminants. The loss of eelgrass habitat encompasses a decrease in coverage, a decrease in density of stems, the displacement of eelgrass by macroalgae, or the conversion of eelgrass meadow to open bottom with sand or mud sediments. Macroalgal mats are less suitable than eelgrass as a refuge for finfish, and the bottom of the macroalgal mat may be hypoxic.

The benthic community can be adversely affected by loss of eelgrass, toxic and hypoxic conditions and macroalgal mats. Shellfish and other benthos are also sensitive to the degree of sedimentation in breeding areas, the presence of critical habitats such as eelgrass beds and wetlands, and the extent of recreational and commercial harvesting mortality, including catch and by-catch. The presence of eelgrass beds and sufficient water quality are thought to be the critical elements for supporting the appropriate habitat to maintain and promote a diverse and abundant estuarine benthic faunal community.

Spawning trout are susceptible to water quality changes. They depend on swiftly flowing, cold waters that are high in dissolved oxygen. Alewife herring, which travel to John's Pond to spawn, rely on sufficient water depth to traverse the bogs near the pond. Drops in the water table or reduced flow can prevent access to spawning areas.

Each of the pathways from source to endpoints was created based on assumptions, or risk hypotheses, about how stressors are affecting or are expected to affect targeted assessment endpoints. They were derived from available information on the watershed from ecological theory on how systems function, and from relationships established in other watersheds that are expected to be consistent. The risk hypotheses developed for each assessment endpoint provide the foundation for evaluating the cumulative and combined risk of more than one stressor.

Each of the stressors identified in the watershed has more than one source contributing to stress in the watershed. As noted previously, nutrients in the form of nitrogen and phosphorus in groundwater are chemical stressors implicated as a major cause of nuisance macro algal blooms and eelgrass decline in the bay and increasing phytoplankton blooms in ponds. Chemicals that might be toxic to aquatic organisms are coming from the MMR contaminant plumes, storm drainage ditches, and nonpoint sources such as road runoff, migration of pesticides, septic system leachate, and atmospheric deposition. Suspended and resuspended organic matter is a physical stressor that increases turbidity and decreases light penetration to eelgrass beds. Physical alteration of estuarine habitat includes increased sediment disturbance, bottom disruption, and shading from dock construction; mechanical disruption from clam digging, boat propellers, and moorings, and habitat fragmentation that results from these activities. Hydrologic modification is another physical stressor that results in altered stream flow patterns and reductions in the flow volume, velocity, and path of rivers and results in loss of spawning habitat for anadromous fishes. Fishes are being harvested from the estuary and rivers and ponds, as well as from offshore, affecting population abundances and the composition of aquatic communities. Another potential biological stressor in the estuary is eelgrass wasting disease caused by the slime mold (*Labyrinthula*).

Analysis Plan

A large number of assessment endpoints were identified in this risk assessment. A comparative risk analysis was conducted by the risk assessment team to help define which stressors, assessment endpoints, and relationships should be examined further. For the preliminary analysis, stressors were ranked in terms of potential risk to all resources in the watershed, using a "fuzzy set" decision analysis method that is based on best professional judgment. The analysis ranks the stressors in order of greatest overall contribution of risk to the endpoints, based on an ordinal effect of a stressor on that endpoint, ranging from no effect to severe effect. The results of the comparative analysis ranked nutrients first, followed by physical alteration and toxic chemicals, then harvest and flow alteration, and finally suspended sediments and eelgrass disease.

Based on the comparative risk analysis, and prevailing scientific opinion prior to the analysis, excess nutrient loading is the principal stressor that prevents most of the management objectives from being met. Thus, further analysis to be conducted for the ecological risk assessment of the Waquoit Bay watershed will identify and address critical gaps in the relationship between nutrient loading and assessment endpoints. The first part of the analysis will develop a predictive model of the response of the extent and cover of eelgrass (ecological effect) to nutrient loading (exposure) in estuaries of Cape Cod. The second part of the analysis will predict future nutrient loading to Waquoit Bay under various scenarios of development.

The approach will be to develop one or more regression models of eelgrass cover in similar estuaries found on Cape Cod. Eelgrass cover in each estuary, digitized from a series of aerial images, will be the response variable. The principal predictive variable will be nitrogen loading, estimated for near and more distant sources in each estuary using extant N loading models. An alternative model will use watershed land use directly as a predictive variable. The objective is to develop predictive relationships between estimated nitrogen loadings (from all sources) and eelgrass cover in Cape Cod estuaries, to be applied to predicting the response of Waquoit Bay to future changes in N loading.

Achieving low nitrogen loading to Waquoit Bay will require nitrogen source control, as well as a sufficient lag time to allow nitrogen currently in the ground water to be flushed out. The travel times of ground water vary across the watershed, thus, nitrogen loading to the estuary is not a function of land use at any one point in time. A second analysis will be conducted to examine the time lag between contamination of ground water at the point of recharge and discharge to the estuary. Nitrogen loading rates provided by the model will then be plotted against measures of ecological effects. The two sets of models and their estimated uncertainties can then be used to predict the effects of different nutrient management scenarios for Waquoit Bay.

INTRODUCTION

Waquoit Bay is a small estuary on the south coast of Cape Cod, Massachusetts, prized by residents and visitors for its aesthetic beauty and recreational opportunities. The watershed covers more than 53 square kilometers (about 21 square miles) of freshwater streams and ponds, salt ponds and marshes, pine and oak forest, barrier beaches, and open estuarine waters. It provides a home, spawning ground, and nursery for a diversity of plant and animal life including piping plovers, least terns (endangered birds), the sandplain gerardia (an endangered plant), and alewife, winter flounder, blue crab, scallops and clams, and anadromous and catadromous fish. But the bay is changing. Eelgrass that provides life to many animals in the bay is being replaced by thick mats of macroalgae. This has resulted in fish kills and the loss of bay scallops. The aquifer underlying the watershed, which provides the communities of Falmouth, Mashpee, and Sandwich their sole source of drinking water, is contaminated by plumes from a Superfund site. Land development is changing the landscape and contributing nutrients and contaminants to the bay. Local communities are concerned for their health and the value the bay adds to their lives.

Worldwide, other estuaries are experiencing similar water quality problems as a result of increasing numbers of people moving to coastal areas (Submerged Aquatic Vegetation Workgroup, 1995). The history of Waquoit Bay in Falmouth and Mashpee illustrates this trend and the struggle between traditional economic growth and conservation of natural resources. Initially valued for hunting, farming, and fishing, Waquoit Bay now primarily provides aesthetic and recreational opportunities (WBNERR, 1989), demands that have generated residential development and business for local marine-dependent industries. Across Cape Cod more than 65,000 permits for single-family homes were authorized between 1970 and 1989, a major portion of which were in Falmouth and Mashpee (Culliton et al., 1992).

The environmental problems Waquoit Bay faces include eutrophication, habitat loss, and resource depletion (WBNERR, 1989). These changes led to the designation of Waquoit Bay as an Area of Critical Environmental Concern (ACEC) in 1979 by the Commonwealth of Massachusetts. In 1988, the federal government and State of Massachusetts formally established the Waquoit Bay National Estuarine Research Reserve (WBNERR). The estuary is a study site under the Waquoit Bay Land Margin Ecosystems Research (LMER) project funded by the National Science Foundation (NSF), the U.S. Environmental Protection Agency (EPA), and the National Oceanic and Atmospheric Administration (NOAA). This is a multidisciplinary project studying the effects of changing land use patterns on ecosystem function. LMER scientists, water resource scientists from the Cape Cod Commission for regional planning, and scientists from the Buzzard's Bay National Estuary Program are evaluating nutrient loading calculations and management options for Waquoit Bay. In April 1995, a new U.S. Fish and Wildlife Refuge was established that will provide a contiguous arc of undeveloped land on the bay. In place also are management plans for federally endangered and otherwise protected species such as piping plovers, least terns, and roseate terns. In May of 1994, Waquoit Bay was declared a Federal No-Discharge Zone, offering some protection against dumping of boat wastes. Increased recreational boating and a proliferation of docks led to new regulations on dock construction in the ACEC management plan. Along with Waquoit Bay, the trout spawning reach of the Quashnet River has been designated an ACEC and the river classified as Class B, to be used for protection and propagation of fish, other aquatic life and wildlife and for primary and secondary-contact recreation (Baevsky, 1991).

EPA Region 1 formally nominated the Waquoit Bay watershed in 1993 for inclusion in an EPA-sponsored project to develop watershed-level ecological risk assessment case studies. Waquoit was selected as one of five watersheds because of interest by local, state, and federal organizations in the watershed, the type of watershed (estuarine), the diversity of stressors (e.g., nutrients, sediments, obstructions, ground water contamination), willingness by the WBNERR and EPA Region I to lead the risk assessment team, and a substantial existing database. Although significant research has been completed in the watershed to date, the value added by conducting a risk assessment in the Waquoit Bay watershed is based on (1) a focus on multiple stressors and relative risk, (2) identification of significant data gaps and design of a research agenda that is more balanced and broad-based, and (3) an interpretation of risk that is useful for pending management decisions.

This document describes the work done by an interdisciplinary and interagency team of scientists and managers (see Appendix A) to develop the Waquoit Bay watershed ecological risk assessment. It is organized into two sections. The first, on the management goal for the watershed, presents the goal and the process used to establish it. The second section is the problem formulation for the risk assessment. The analysis and risk characterization phases of the risk assessment are under development.

1.0 PLANNING THE RISK ASSESSMENT

The Waquoit Bay watershed ecological risk assessment was based on a proposal by managers in WBNERR and EPA Region 1 who were concerned about the changing quality of the Bay. Based on this interest, a risk assessment team was assembled (Appendix A) and planning for the risk assessment began in 1993.

The objectives of the planning were to establish clear and agreed-upon goals for watershed resources, to determine the purpose for the risk assessment within the context of those goals, and to agree on the scope and complexity of the risk assessment (USEPA, 1996). One of the principal challenges for meeting planning objectives for this risk assessment was to develop a management goal for watershed resources that diverse members of the community could support. To meet the requirements of planning, the risk assessment team (the Team) worked with watershed risk managers (the Managers) to develop and implement a process for ascertaining the interests and goals of the public; local, state, and federal organizations; and other resource managers in the watershed. Below is a description of the goal and an explanation of how it was derived and interpreted. The scope, complexity, and focus of the assessment are also delineated.

1.1 Establishing the Management Goal

The management goal for Waquoit Bay was generated through discussions with risk managers and risk assessors in the watershed, participation on the Team by local risk managers, and dialogues with interested parties concerned about watershed resources.

1.1.1 The Management Goal

Reestablish and maintain water quality and habitat conditions in Waquoit Bay and associated wetlands, freshwater rivers, and ponds to (1) support diverse, self-sustaining commercial, recreational, and native fish and shellfish populations and (2) reverse ongoing degradation of ecological resources in the watershed.

1.1.2 Interpreting the Management Goal for Risk Assessment

The management goal is a qualitative statement that captures the essential interests expressed by different management organizations and the public in the Waquoit Bay watershed (see Section 1.1.3). In order for the management goal to support an ecological risk assessment, the goal was evaluated by the Team and interpreted as 10 management objectives believed to be required to achieve the goal (see Table 1). These objectives were intended to state explicitly what kinds of management results were implied in the general goal statement. By performing this kind of evaluation, the Team provided feedback to the managers on the ecological characteristics of the goal, developed a systematic process for identifying assessment endpoints that could be directly linked to the management goal, and provided a way to measure achievement of the goal for risk managers.

Table 1 is partitioned into three categories. The "Estuarine and Freshwater" category includes three objectives that are common to both surface water types. Four objectives under the "Estuarine" category and three objectives under the "Freshwater" category are unique to those waters. The 10 objectives are stated as goals for specific aspects of exposure, stressors, and valued ecological resources. Assessment endpoints were selected and justified based on these objectives (see Section 2.3). Although the goal was developed by the Managers, the specific management objectives were generated by the Team based on available information on watershed resources. The objectives were then provided to managers for their consideration and approval (see Section 1.1.3).

Table 1. The Waquoit Bay watershed management goal, interpreted as 10 management objectives that are implied by and needed to achieve the goal.

Affected Area	Number	Component Management Objective
Estuarine and Freshwater	1	Reduce or eliminate hypoxic or anoxic events
	2	Prevent toxic levels of contamination in water, sediments, and biota
	3	Restore and maintain self-sustaining native fish populations and their habitat
Estuarine	4	Reestablish viable eelgrass beds and associated aquatic communities in the bay
	5	Reestablish a self-sustaining scallop population in the bay that can support a viable sport fishery
	6	Protect shellfish beds from bacterial contamination that results in closures
	7	Reduce or eliminate nuisance macroalgal growth
Freshwater	8	Prevent eutrophication of rivers and ponds
	9	Maintain diversity of native biotic communities
	10	Maintain diversity of water-dependent wildlife

1.1.3 Process for Selecting the Management Goal

The management goal was developed through a multistep process initiated and completed by the Team. Three principal approaches were used: a public meeting, evaluation of written goals by organizations having jurisdiction over or interest in the ecological resources of the watershed, and a meeting of members of these organizations to review and approve the management goal and Team-derived objectives.

Public Meeting. EPA, in conjunction with WBNERR, held a public forum on September 21, 1993. The forum was advertised and reported in local newspapers (Appendix B) to receive input on what was valuable to the public about the Waquoit Bay watershed and what the public believed were the principal stressors placing these values at risk. Each participant was asked to answer two questions: (1) What do you value in the watershed? (2) What is placing those values at risk? Participants provided a substantial list of values and an array of chemical, physical, and biological stressors (Appendix C). This feedback provided a basis for Team generation of a working management goal, which was used to guide the collection and evaluation of available information during the initial stages of problem formulation.

Organizational Goals. The written goals established for Waquoit Bay by local, regional, and national resource management organizations with jurisdiction in the watershed were collected by the Team and summarized. Based on written documentation published by the organizations, or as represented by statute, the Team generated short descriptors which are provided in Table 2. These organizational goals were used to refine the risk assessment management goal and develop the 10 management objectives.

Risk Management Team Consensus. To finalize the management goal, members of concerned organizations (see Appendix D) were invited to a meeting sponsored by WBNERR in Waquoit on February 24, 1995. The working management goal, the summary of organizational goals, and the interpretation of the goal as 10 management objectives was presented to meeting participants. The management goal and objectives for the risk assessment were approved as modified by the organization representatives at the meeting. Participants in this meeting are considered the risk management team for the risk assessment. They will be principally responsible for implementing management plans in Waquoit Bay.

Table 2. Summary statement of goals and objectives of federal, state, and local organizations with management jurisdiction in Waquoit Bay.

Organization	Example Goal
Association for the Preservation of Cape Cod	"Assist [other organizations] ... to decrease nitrogen loading to Waquoit Bay"
Atlantic States Marine Fisheries Commission	Coordinates marine fisheries management in state waters
Cape Cod Commission	"Protect the region's resources .... protect and improve coastal water quality and shellfish habitat"
Citizen Action Committee (formed of representatives from other groups)	Reverse ongoing degradation and protect water quality and habitats of Waquoit Bay
Citizens for the Protection of Waquoit Bay	"Preservation of the environment (physical, aesthetic and otherwise) and the natural resources of the Waquoit Bay area"
Massachusetts Coastal Zone Management	"Protection of natural and cultural resources in the coastal zone"
Massachusetts Department of Environmental Protection	Non-degradation of coastal waters (Waquoit Bay is class SA, or waters with DO > 5 mg/L and where shellfish do not require depuration)
National Marine Fisheries Service	Implements Magnuson Act for marine fisheries management in federal waters, and the Marine Mammal Protection Act (with USFWS)
NOAA National Estuarine Research Reserve System	"Establish and manage a national network of protected areas .... Mobilize federal, state and community resources to mutually define and achieve coastal protection and management goals and objectives"
U. S. Army Corps of Engineers	Regulation and maintenance of navigational channels in rivers and harbors; oversight over coastal armoring; issue permits for construction in waters and wetlands (Section 404)
U. S. Environmental Protection Agency	Implementation of national environmental laws, including the Clean Water Act
U. S. Fish and Wildlife Service	Implementation of the Endangered Species Act; management of National Wildlife Refuges
Waquoit Bay National Estuarine Research Reserve	"Protect in perpetuity for the purposes of research and education; .... Promote stewardship and estuarine awareness through outreach activities..."
Waquoit Bay Watershed Intermunicipal Committee	"Evaluate possible options to improve water quality in the watershed"

1.2 Management Decisions

The ongoing and easily observed degradation occurring in Waquoit Bay is causing managers in the watershed to look for better ways to manage valued resources. Key issues requiring decisions include nutrient control, reducing bacterial contamination in shellfish, and containment of ground water contamination. To achieve the goals for the watershed, there might also be other important considerations.

Nutrient inputs to the watershed are recognized as a serious problem. Managers are considering the feasibility of installing denitrification technology and alternative sewage treatment for homes and businesses along the bay and in the surrounding watershed. Treatment of sewage is a critical issue that must be addressed on technical, financial, and ecological grounds. The risk assessment is to address the impact of nitrogen in the watershed and predict the effectiveness of nitrogen reduction in meeting management goals. Bacterial contamination of shellfish beds is a related concern for septic system management.

Managers are evaluating alternative management options for protecting the watershed from ground water contaminants now reaching the ponds and expected to reach the estuary within 10 years. A proposed extraction and treatment plan might result in more significant ecological effects than will occur if exposure to the contaminants is allowed. Alternative options must be considered.

Boating and clamming activities are increasing in the Bay and might require more stringent controls. Location of boating traffic and clamming could be important to reestablishing important infaunal and epifaunal benthic communities. Better enforcement of speed limits and fishing activities might be necessary.

Among the more critical considerations for many of these stressors is land development and use. Recommendations concerning land use that are based on ecological risk are desired.

1.3 Purpose, Scope, and Complexity of the Risk Assessment

The purpose of this risk assessment was to determine what and how human activities are contributing to ongoing degradation of valued ecological entities in the Waquoit Bay watershed. Specifically, it was designed to evaluate the relative contributions of dominant stressors to support management decisions about changing land use, installing new septic system treatment technology, evaluating management options for cleanup of groundwater contamination, identifying key research needs, and providing the framework for predicting what effect possible management actions will have on key ecological resources at risk. The risk assessment was not legally mandated. The WBNERR is particularly interested in the risk assessment as a vehicle for developing a research agenda. The risk assessment will also serve as a source of information as several governmental organizations begin management of contaminated ground water.

The intended scope of the assessment was to address individual stressors' effects and the combined risk of multiple stressors within the last 10 years in comparison with historical records spanning 50 years. Although significant data on the watershed have been collected, most are related to nutrient inputs and "build-out" (i.e., residential and other land development), with additional data on groundwater contamination. Relatively few data are available on the biological changes associated with specific levels of these stressors or other stressors identified by the Team, although this is beginning to change, in part due to the development of problem formulation. While the problem formulation is as broad as possible, the scope of the risk assessment was narrowed to reflect data limitations. Where data are few, the Team identified key missing information and made recommendations on types of data collection for future work to assess the combined impacts of multiple stressors.

During problem formulation, the intent of the Team was to be as complete and comprehensive as possible about relationships between stressors and ecological values selected as assessment endpoints within the 21-square-mile area representing the surface watershed. The conceptual models developed include all identified sources of stress, stressor types, effects, and a selection of assessment endpoints that best represent the management goal for the fresh and estuarine waters of the watershed. The terrestrial component is not represented in the risk assessment aside from one assessment endpoint on water-dependent wildlife habitat and recognition that terrestrial impacts influence what occurs within water. Although the ground water component underlies the watershed, it is not confined within the 21-square-mile area and therefore represents a scale larger than that of this risk assessment.

Once conceptual models were developed, it was the intent of the Team to select specific stressor-assessment endpoint relationships to pursue based on both the importance of the relationship to perceived overall risk and the amount of data available to evaluate the relationship. In some cases assumptions were made to allow analysis, understanding that these assumptions add to the uncertainty of results. The Team will attempt to evaluate the combined risk of multiple stressors.

Limitations in the risk assessment reflect significant limitations on available resources. All members of the risk assessment team are professionals from federal, state, and local organizations, who provided their expertise and time without grant or contract funds. Limited contract support was used to provide some assistance to the team. Although efforts were made to foster more academic participation, this was directly limited by the Team's inability to provide funding. Key researchers in the watershed were included as resource people. No new data were collected to conduct this assessment, but best efforts were made to use available data effectively. The success of this risk assessment was based on effective leveraging of available resources. Limitations, although significant, did not prevent the achievement of important results.

2.0 WAQUOIT BAY PROBLEM FORMULATION

To develop problem formulation, a formal process was used to generate preliminary hypotheses about why ecological effects in Waquoit Bay have occurred and to predict changes in ecological responses both to continuing stressor inputs and to identified management actions that might reduce stressor inputs. In the watershed, stressors of long duration were identified, as well as potential risks from expected future human activities. To complete problem formulation, it was necessary to evaluate historical records on the ecological characteristics of the bay and the dominant human activities over comparable time periods, as well as to evaluate current status. This information provided the basis for predicting ecological responses to management actions and future stressors.

The Waquoit Bay problem formulation is based on an assessment of available information that provided the foundation for risk hypothesis development. A brief summary of key information is provided below and supplemented by more detailed information in Appendix E. Based on the management goal and available information, assessment endpoints were selected by the Team. These assessment endpoints were used as the focus in the development of conceptual models and the analysis plan. The following sections describe the result of these steps in the problem formulation process.

2.1 Assessment of Available Information

The initial step in problem formulation was to identify and assess available information on the characteristics of the watershed, observed ecological effects, and possible stressors on the system. This section provides a brief overview of information on the Waquoit Bay watershed. It highlights the information most pertinent to understanding the risk assessment and is not intended to be comprehensive. More comprehensive information is provided in Appendix E.

2.1.1 Characterization of the Ecosystem at Risk

The Waquoit Bay watershed covers more than 53 square kilometers (about 21 square miles) and spans parts of the towns of Falmouth, Mashpee, and Sandwich on the south coast of Cape Cod, Massachusetts (Babione, 1990; Cambareri et al., 1992, 1993). It extends 8 kilometers (5 miles) from the head of the bay to the regional ground water divide in the vicinity of Snake Pond (Figure 1). The watershed includes estuarine and freshwater systems encompassed in seven subwatersheds (Childs River, Sage Lot Pond, Quashnet River, Eel Pond, Head of the Bay, Hamblin Pond, and Jehu Pond) and four large ponds (Ashumet, Johns, Snake, and Flat).

The Waquoit Bay watershed, like all of Cape Cod, is a geologically young landform composed of glacial materials deposited on top of bedrock toward the end of the Wisconsinian Glacial Stage about 12,000 years ago (LeBlanc et al., 1986; Oldale, 1992). The watershed lies entirely within the Mashpee pitted outwash plain. The term pitted refers to sites where blocks of glacial ice were buried during glacial retreat. When the blocks melted, depressions formed and filled with water, creating numerous kettle ponds (e.g., Ashumet and Johns ponds).

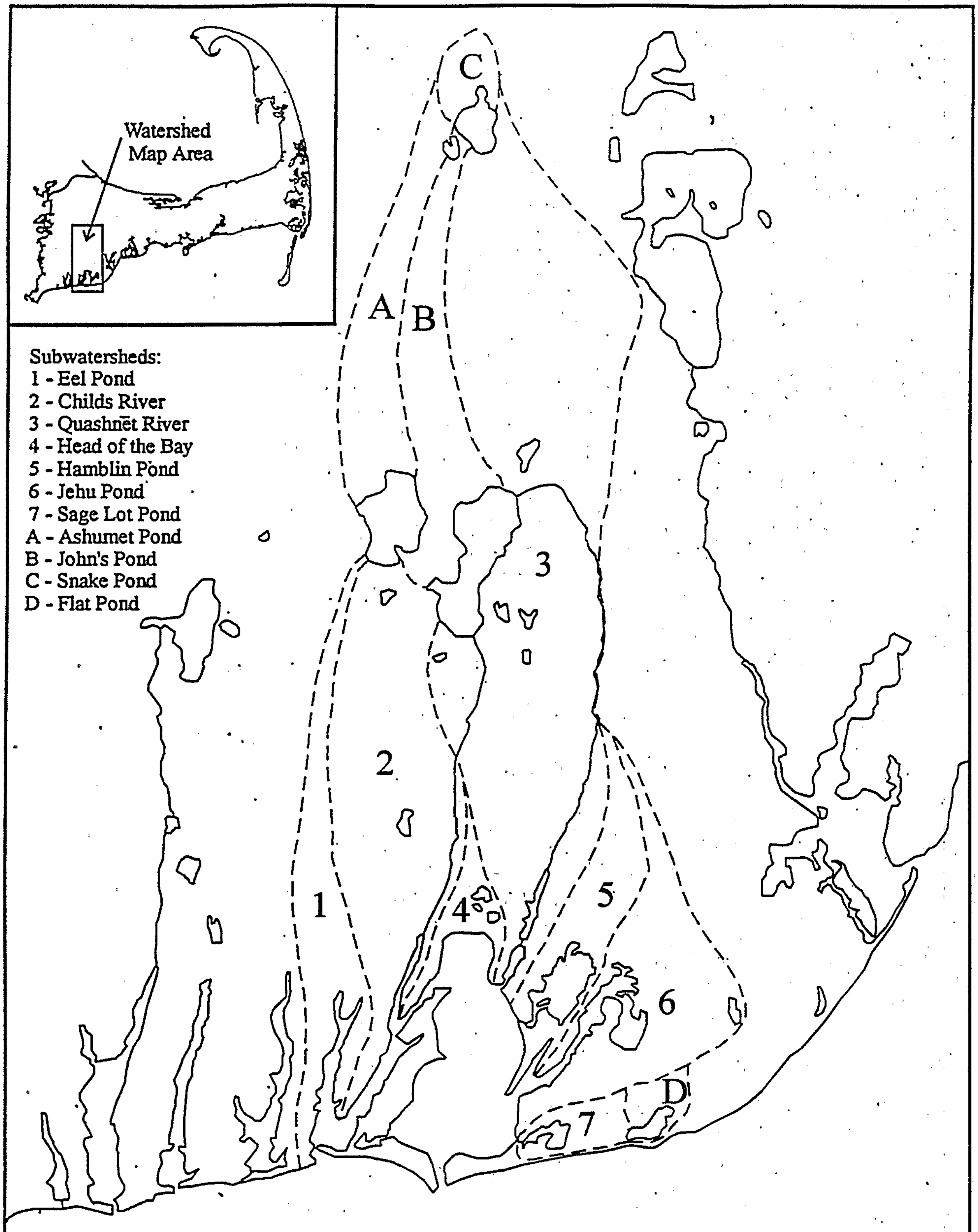

Figure 1. Waquoit Bay watershed and subwatersheds (Brawley and Sham, in prep.).

Waquoit Bay may have originated as a kettle pond whose southern margin was flooded by subsequent sea level rise. The bay is a shallow estuary approximately 1.2 km (4,000 feet) wide and 3.4 km (11,000 feet) long with an average depth of 0.9 m (3 ft). Tidal exchange to Vineyard Sound occurs through two dredged channels and a breach caused by Hurricane Bob in 1991. The action of winds, waves, and currents continually erodes and displaces the loose glacial sand and gravel forming coastal sand dunes, sea cliffs, barrier beaches, and salt marshes.

The watershed's climate is maritime, with warmer winters and cooler summers than more inland areas of New England, and annual precipitation between 107 and 112 cm (42 and 44 in). Fifty percent of fresh water entering the Waquoit Bay estuary is from precipitation-23 percent from direct precipitation and 27 percent from groundwater recharge (Cambareri et al., 1992). Ground water recharge is approximately 45 percent of the total precipitation. The remaining 50 percent of fresh water entering Waquoit Bay comes from the Quashnet and Childs Rivers. The porous, sandy glacial soils promote rapid percolation of rain, nutrients, and contaminants into the subsoil and ground water. Little surface runoff occurs.

Cold south-flowing Gulf of Maine waters and warm north-flowing Gulf Stream waters mix off the coast of Cape Cod to form a biological transition zone between the Virginian (temperate) and Acadian (boreal) biogeographic provinces (Ayvaziam et al., 1992), producing more diverse biotic communities and habitats than occur in either province. The combination of salt, estuarine, and freshwater systems within the watershed augment this diversity. Critical resources in the Waquoit Bay watershed include freshwater wetlands on the pond shores; anadromous fish runs in the rivers; salt marshes, eelgrass beds, and barrier beaches in the estuary; and upland woodlands (VanLuven, 1991). The surface water ecosystems support a variety of food resources for aquatic, terrestrial, and avian wildlife and include commercially and recreationally important finfish and shellfish.

2.1.2 Ecological Effects

Water resources in the Waquoit Bay watershed are exhibiting signs of water quality degradation. Waquoit Bay is becoming eutrophic, as evidenced by excess algal growth that decreases light penetration. Light-dependent eelgrass beds have almost disappeared from the bay. Documented declines in numbers of winter flounder, tauog, summer flounder, blue crabs, bay scallops, and other eelgrass- dependent species parallel the loss of eelgrass. The bay scallop, an important commercial and sport species, has virtually disappeared. When several consecutive cloudy days occur during summer months, mass deaths of aquatic organisms occur, presumably from respiring algae that deplete dissolved oxygen. Increasing incidents of shellfish bed closure from bacterial contamination are also a source of concern in the estuary.

Freshwater components of the watershed also are changed. Stream flow alterations have resulted in a loss of reproductive habitat for traditional herring runs and migratory fish spawning areas. Malformations and tumors in fish living in the kettle ponds may be indicative of exposure to contaminants. Freshwater ponds are showing increasing levels of algal growth, which is likely to alter the aquatic community. Targeted changes of concern include:

- Blooms of phytoplankton and macroalgae.
- Loss of eelgrass habitat and associated species, in particular, bay scallops.
- Changes in species composition and declining abundances of commercially important finfish and shellfish.

- Mass mortalities of fishes and invertebrates in the upper bay and ponds.

- Reduced water flows in herring runs and trout streams.

2.1.3 Sources and Stressors

Multiple sources of stress were identified in the watershed. For each of these sources, multiple stressors could also be identified. More than one source may produce the same complement of stressor types, but the exposure pathway and specific characteristics of the stressors may vary. The following highlights key sources and key stressor types with minimal discussion of exposure pathways and characteristics. Refer to Appendix E and the section on conceptual models (Section 2.3) for more information.

Sources. The main sources of stress identified in the Waquoit Bay watershed include agriculture, atmospheric deposition, residential development, industrial uses, and marine activities. Changing land and water use patterns along the coastal and upland areas in the Waquoit Bay watershed are largely responsible for increasing stressors in the watershed (Appendix F). Some of these affect local resources but occur outside the watershed, including armoring of the coast, which shifts sediment deposition along barrier beaches; offshore fishing, which depletes stocks of commercially valuable species; and wet and dry atmospheric deposition from motorized vehicles and industries. Principal sources of stress in the watershed include the following:

- Cranberry cultivation which results in the use of fertilizers, the application of pesticides and herbicides, and the construction of flow control structures that alter surface water flow.

- Atmospheric deposition from local and regional automobiles, lawn mowers, and motor boats; on a larger spatial scale, nutrients (in the form of nitrogen oxides, NOx's) from industrial emissions, and toxic chemicals, including mercury, that originate outside the watershed.

- Residential development, which contributes nutrients to the system through fertilizer use on lawns, golf courses, and gardens, and on-site septic systems; housing and road construction, which results in habitat loss, sedimentation, and additional runoff of nutrients, contaminants, and sediments from construction sites, and an increase in impervious surfaces; and private and municipal well development, which alters ground water flow.

- Industrial discharges to groundwater from the Massachusetts Military Reservation (MMR), a Superfund site on the upper western portion of Cape Cod that is contaminating ground water (a sole source aquifer for drinking water) with chlorinated solvents and fuel constituents; its sewage treatment facilities contribute in phosphorus to ponds; and the MMR contributes increased runoff of nutrients, sediments, and contaminants from impervious surfaces.

- Marine activities including construction and operation of marinas; and recreational boating and dock and pier construction which disturbs sediments, alters habitats, and contributes nutrients and contaminants; dredging and shoreline modification for waterway maintenance, which disturbs sediments; shellfishing which disrupts eelgrass habitat, resuspends sediments, and adds harvest pressure; and recreational fishing in the estuarine, river, and pond environments, which also adds harvest pressure.

Stressors. Seven principal stressors were identified-two chemical, three physical, and two biological. Each stressor has more than one source contributing to stress in the watershed. Each stressor was characterized on the basis of its type, its mode of action, and the general ecological effects that might result from exposure to the stressor. In addition, information on the intensity, frequency, duration, and spatial scale were reviewed for each stressor where available. Principal stressors include:

- Nutrients, which are implicated as a major cause of nuisance macroalgal blooms and eelgrass decline in the bay (Table 3) and increasing phytoplankton blooms in ponds in part because of the porous, sandy soils in the watershed, which promote rapid percolation of nutrients from land deposition, septic systems, and other inputs into ground water.

- Chemicals that may be toxic to organisms in the bay, streams, and ponds, primarily mobilized chlorinated solvents and fuel constituents from MMR contaminant plumes, open storm drainage ditches, and nonpoint sources such as road runoff, migration of pesticides, on-site septic disposal system leachate and atmospheric deposition of mercury, lead, and organic contaminants (light fraction polynuclear aromatic hydrocarbons or PHAs).

- Suspended and resuspended sediments that increase turbidity and decrease light penetration to eelgrass beds, and can weigh down eelgrass blades both directly and by increasing epiphyte weight; and, as a result of loss in eelgrass, a shift in deposition.

- Physical alteration of estuarine habitat including increased sediment disturbance, bottom disruption, and shading from dock construction; mechanical disruption from clam digging, boat propellers, and moorings, and habitat fragmentation that results from these activities.

- Altered flow or hydrologic modification where the flow volume, velocity, and path of rivers results in loss of spawning habitat for anadromous fishes.

- Finfish harvest pressure, which directly affects fish mortality in offshore species from commercial fishing activities, and recreational fish in freshwater rivers and ponds.

- Eelgrass wasting disease caused by the slime mold (*Labyrinthula*), which can act synergistically with stress on eelgrass from reduced light conditions.

Table 3. Nitrogen loading to water table, chlorophyll concentrations, and mean (± standard deviation) biomass of macrophytes in three selected subestuaries of Waquoit Bay (Adapted from Valiela et al. 1992).

Subwatershed	N loading to water table (kg N yr^{-1})	Chlorophyll concentrations at mouth (mg m^{-3})	Total macroalgal biomass (g m^{-2})	Eelgrass biomass (g m^{-2})
Childs River	14209	25.5 ± 7.6	335 ± 39.8	0
Quashnet River	14534	5.9 ± 1.7	150 ± 14.3	0
Sage Lot Pond	331.5	3.9 ± 1.2	90 ± 12.1	117 ± 12.6

2.2 Assessment Endpoint Selection

The Team's selection of assessment endpoints was based on societal values expressed in the management goal and objectives, as well as an evaluation of available information to ensure that the endpoints were ecologically relevant in the watershed and were susceptible to the identified stressors. The assessment endpoints are measurable attributes of valued resources that include both an entity (e.g., eelgrass) and a measurable attribute (e.g. areal extent). They provide direction for the assessment and are the basis for the development of questions, predictions, models, and analyses. The Team's identification of an assessment endpoint does not imply that data currently exist in Waquoit Bay to quantify attribute changes. Assessment endpoints are only required to support the ability to collect data for quantification.

2.2.1 The Assessment Endpoints

Eight assessment endpoints were selected to represent estuarine and freshwater components of the ecosystem and ecological and human health concerns. In some cases overlap among assessment endpoints was recognized and endpoints were combined or eliminated later in the process. The assessment endpoints selected for the Waquoit Bay watershed ecological risk assessment include:

- Estuarine eelgrass habitat abundance and distribution
- Resident and juvenile nursery estuarine finfish species diversity and abundance
- Clam and other benthic invertebrate diversity, abundance, and distribution
- Migratory brook trout and alewife herring reproduction
- Freshwater stream benthic invertebrate diversity and abundance
- Freshwater pond trophic status
- Water-dependent wildlife species feeding and nesting habitat
- Bacterial and contaminant content of fish and shellfish

2.2.2 Endpoint Description and Rationale

Assessment endpoints were selected based on three criteria: how well they represent the management goal (societal value), how well they represent ecological integrity in the ecosystem (ecological relevance), and how likely they are to be exposed to and adversely affected by known stressors (susceptibility). To judge societal value, each endpoint was evaluated relative to the 10 management objectives identified during planning (Table 1, Section 1.1.2). Table 4 shows which management objectives each endpoint addresses. Ecological relevance and susceptibility were both evaluated based on available information on ecosystem structure and function and known and predicted stressors. In the descriptions below on the assessment endpoints, the rationale for selection based on these three selection criteria is provided.

Table 4. Relationship of assessment endpoints to management objectives.

Assessment Endpoint	Management Objective Number									
	1	2	3	4	5	6	7	8	9	10
Estuarine eelgrass habitat abundance and distribution		X	X	X	X		X			
Estuarine Finfish Species diversity and abundance	X	X	X	X			X			
Benthic invertebrate diversity, abundance and distribution	X	X	X	X	X		X			
Freshwater Migratory fish reproduction		X	X						X	
Stream benthic invertebrate diversity and abundance		X	X					X	X	
Freshwater pond trophic status								X		
Water-dependent wildlife species feeding & nesting habitat		X								X
Bacterial & contaminant content of fish and shellfish		X				X				

Considerable overlap and interdependence among objectives and potential endpoints are recognized. For example, objective 5 (reestablishment of scallops) would require achieving objective 1 (elimination of hypoxia), objective 2 (prevent toxicity) to prevent scallop death, objective 4 (re-establishment of eelgrass), and objective 7 (eliminate macroalgae) to provide suitable habitat. Objective 4 (juvenile scallop habitat) would require achieving objective 7 (eliminate macroalgae) because local hypoxia (objective 1) is caused by decaying algae at the bottom of the mats, and macroalgae shade and replace eelgrass. This type of evaluation was used to identify multiple sources of stress and the variety of possible pathways for loss of an ecological value. The objective is to identify the complement of necessary and sufficient conditions for achieving management goals.

Each assessment endpoint is described below to highlight its characteristics as they relate to ecological relevance, susceptibility to known stressors, and societal value, with specific reference to the management objectives.

Estuarine eelgrass habitat abundance and distribution. Eelgrass (*Zostera marina*) is a rooted vascular plant that grows subtidally on mud to gravel bottoms in zones of fast-moving or quiet waters where salinity ranges between 20 and 32 parts per thousand. Eelgrass roots and rhizomes decrease erosion and increase sedimentation. Eelgrass blades promote deposition by interrupting water flow, and trapping suspended sediments and particulate organic matter, thereby adding to the available food within the meadow (Short, 1984, 1989).

Eelgrass habitat abundance and distribution was selected as an assessment endpoint because eelgrass beds provide prime living, feeding, and nursery habitat for a large and significant aquatic community including juvenile scallops, invertebrates, and forage fish that sustain larger fish species (Heck, 1989; Thayer et al., 1989; management objectives 3 and 4). Eelgrass is highly susceptible to water quality conditions and requires clear waters with ample light penetration for photosynthesis. Shading by algae and suspended sediments directly impacts eelgrass growth. Excessive growth of macroalgal mats has displaced eelgrass in Waquoit Bay (objective 7).

Abundance and distribution were selected as measurable attributes of eelgrass to represent estuarine condition. Existence of eelgrass is one of the best indicators of estuarine quality, and the presence of a diverse aquatic community (e.g., greater species diversity and abundance was found in eelgrass beds compared to adjacent unvegetated areas in Waquoit Bay and Nauset Marsh on Cape Cod (Valiela et al., 1992; Heck et al., 1989)). Measures of quality and density were not chosen for eelgrass attributes because of the greater difficulty in obtaining information on plant species composition, shoot density, and blade stature. Although these variables influence physical structure, food availability, and physical suitability of these areas for fish, in the absence of toxicity, the presence of eelgrass beds is the best indicator of the presence of a diverse estuarine aquatic community. Both eelgrass and several eelgrass dependent and commercially important species have declined precipitously since the 1950s.

Resident and juvenile estuarine finfish species diversity and abundance. The estuarine finfish community contains resident and transient, and demersal and pelagic species. Fifty-two species have been collected in Waquoit Bay. Of these, mummichug, striped killifish, tidewater silverside, fourspine stickleback, and rainwater killifish constitute 35 percent of the total taxa, and dominate the abundance (46 percent) and biomass (41 percent) of the overall finfish community (Ayvazian et al., 1992). Part-time residents represent a composite of estuarine spawners (e.g., winter flounder and tautog); marine species that are estuarine visitors (e.g., sand lance, summer flounder, and American pollack); nursery species or young-of-the-year (e.g., winter flounder juveniles, mullets, juvenile tautogs, menhaden, Atlantic silversides, bluefish, and bay anchovy); and adventitious species that have a more southern distribution but lack an apparent estuarine dependence (e.g., ladyfish, halfbeak, and crevalle jack).

Resident and nursery finfish were selected for the assessment endpoint because of their importance to commercial and recreational values, their significance to the aquatic community, and their susceptibility to localized impacts on habitat quality. Finfish are susceptible to hypoxic and anoxic conditions (e.g., summer anoxia or hypoxia may impact winter flounder juveniles and mummichugs, objective 1) and toxic contaminants (objective 2). The loss of eelgrass habitat encompasses a decrease in coverage, a decrease in density of stems, the displacement of eelgrass by macroalgae, or the conversion of eelgrass meadow to open bottom with sand or mud sediments.

Macroalgal mats are less suitable than eelgrass as a refuge for finfish, and the bottom of the macroalgal mat may be hypoxic (objectives 4 and 7). Diversity and abundance of resident and nursery finfish were selected as attributes because these measures represent the existence of conditions that support survival, reproduction, and recruitment (objective 3), and some data are also available. Feeding, hiding, reproduction, and recruitment would be important attributes to measure in future studies.

Commercially harvested marine and estuarine adults are not included. They are susceptible to offshore as well as inshore stressors and therefore reflect more regional impacts resulting from harvest pressure, coastal eutrophication, and long-term climate change. These groups were not selected as part of the assessment endpoint because nursery species and year-round resident finfish are better indicators of localized impacts on habitat quality. If resident and nursery species are protected, it is assumed that marine species will also be protected from habitat degradation.

Clams and other benthic invertebrate diversity, abundance, and distribution. Clams and other benthic invertebrates in Waquoit Bay provide major food sources for resident and transient finfish and water-dependent wildlife. Hardshell and softshell clams currently support an important recreational and commercial fishery. Scallops are no longer harvestable. The benthic community can be adversely affected by loss of eelgrass, toxic and hypoxic conditions and macroalgal mats (objectives 1, 2, 4, 5 and 7). Shellfish and other benthos are also sensitive to the degree of sedimentation in breeding areas, the presence of critical habitats such as eelgrass beds and wetlands (objective 4) and the extent of recreational and commercial harvesting mortality, including catch and by-catch (objective 5). The presence of eelgrass beds and sufficient water quality are thought to be the critical elements for supporting the appropriate habitat to maintain and promote a diverse and abundant estuarine benthic faunal community.

Scallops are principally found in eelgrass beds and hardshell and softshell clams inhabit sandy open areas. Since these species are found in different bottom habitats, their abundance and distribution are a good reflection of ecosystem function. Although scallops are specified in management objective 4, they were not explicitly selected as an assessment endpoint because their numbers fluctuate widely in nature, and the absence of scallops cannot be interpreted to mean that the known environmental requirements for scallops are not being met. Since epifaunal invertebrates settle on eelgrass blades and some infaunal invertebrates occur in greater abundance within eelgrass beds, the eelgrass-associated benthic community is being used to represent the ecological requirements for scallops which settle on the blades during their juvenile phase before settling as adults on the surface of the sediments.

Migratory brook trout and alewife herring reproduction. Migratory fish, including anadromous brook trout and alewife herring, use the Waquoit Bay watershed as breeding grounds. Migratory fish provide for a highly valued recreational fishery that has been in decline. The Quashnet River was a prized trout stream, with anadromous or "sea run" brook trout or "salters" in the 1800s. By 1950, industrial and then agricultural demands had destroyed their breeding habitat. It has taken years of effort by Trout Unlimited and the Massachusetts Division of Fisheries and Wildlife to reestablish breeding habitat in about 1.5 miles of the river. The trout species that rely on this river for spawning are susceptible to water quality changes. They depend on swiftly flowing, cold waters that are high in dissolved oxygen. Alewife herring, which travel to John's Pond to spawn, rely on sufficient water depth to traverse the bogs near the pond.. Drops in the water table or reduced flow can prevent access to spawning areas. The Quashnet River and the ground water that feeds it might be tapped for drinking water, possible leading to changes in water quantity while urban development could lead to further water quality problems.

Trout and alewife are sensitive representatives for other migratory finfish. Protecting the ability of migratory finfish to reach freshwater rivers and ponds and find habitat and water quality appropriate for spawning and egg survival meets the management goals for streams and ponds (objectives 2 and 9). Reproduction of migratory fish was selected as the attribute because the key function that the freshwater portions of the watershed provide to migratory fish is reproductive habitat. This attribute is particularly susceptible to the types of stressors likely to impact migratory fish in this watershed.

Freshwater stream benthic invertebrate diversity and abundance. Stream benthic invertebrates serve as a needed food source for migratory and resident fish. Like migratory fish, benthic invertebrates need swiftly flowing, highly oxygenated, high-quality water for their habitat. Benthic invertebrates are excellent indicators of water and sediment quality because they spend most of their life cycle in the stream (often in restricted locations or habitats) and are particularly susceptible to toxics (objective 2), eutrophication effects (objective 8), and sedimentation. Societal value is based on the value of native species (objective 9) and the support the benthic aquatic community provides for fish species (objective 3).

Freshwater pond trophic status. Changes in the tropic status of kettle ponds serve as an indicator of water quality and directly affect ecosystem function (objectives 2 and 8). The susceptibility of ponds to increasing nutrient loads makes this assessment endpoint the best indicator of pond shifts from oligoatrophic to eutrophic status and also addresses community interest in recreational use of the ponds for swimming, fishing, and aesthetic enjoyment.

Water-dependent wildlife species feeding and nesting habitat. Many avian species, including the piping plover, least tern, and roseate tern, nest or forage along the barrier beaches of Waquoit Bay. Other important wetlands in the Waquoit Bay watershed include the salt marshes surrounding the bay and its tributaries, the coastal ponds, and the shorelines of Ashumet and Johns Ponds. Waterfowl are the most societally important wildlife solely dependent on wetlands for breeding, feeding, and migratory needs. Within the ponds, a high diversity of phytoplankton and abundant invertebrates provide food for finfish which, in turn, are prey for osprey. Several avian species that use the ponds are of special concern or threatened, including the marsh hawk and grasshopper sparrow. These species have high societal value. They are susceptible to toxic pollutants originating from MMR, cranberry bogs, and urban development (objective 2). They are also susceptible to habitat loss, both from direct destruction of habitats, and toxicological and hydrological changes that may influence habitat type, quality, and quantity. Significant numbers of bird and mammal species use wetlands and freshwater resources around the ponds and rivers for feeding and nesting. Maintenance of supporting wetland habitats was considered appropriate for meeting management objective 10.

Bacterial and contaminant content of fish and shellfish. The aquatic community of fish and shellfish provides significant recreational and commercial benefits to humans and other organisms in the watershed. Increasing incidents of shellfish bed closures to harvesting because of high bacteria counts are of considerable concern to commercial and recreational interests in the watershed (objective 6). Increasing evidence of malformations in resident freshwater fish in ponds now being contaminated by ground water plumes flowing from the MMR Superfund site are cause for concern, although studies are preliminary and no evidence of chemical contaminants as the caude has been demonstrated (objective 2). Contamination is expected to increase and might be a problem now.

2.2.3 Overlap of Assessment Endpoints and Their Application to the Risk Assessment

These assessment endpoints are used to represent ecological values in the watershed that support management goals. During their selection considerable discussion occurred to determine whether this set of endpoints was sufficient, redundant, or excessive. Several endpoints may be considered redundant but were not eliminated before conceptual model development because of possible insights their use could provide during hypothesis generation and model construction. The team recognized some redundancy but felt that the set best covered the diversity of ecological values and stressors impacting the watershed.

Selection of which assessment endpoints to follow through to analysis occurred during the development of the conceptual models and in the planning of analyses. In some cases only limited data or information is available on an assessment endpoint so for the purposes of this risk assessment, that assessment endpoint can only serve as a focal point for conceptual model development. However, for planning future research the assessment endpoint serves a significant function in defining what research needs to be done in the watershed.

2.3 Conceptual Model Development

The conceptual models developed for the Waquoit Bay watershed represent a series of risk hypotheses about the relationships between particular stressors and ecological effects expected to be observed in each assessment endpoint. Models were developed at several levels of complexity and were done interactively. The general watershed conceptual model (Figure 2) is a broad representation of relationships among human activities in the watershed (sources), the stressors believed to occur as a result of those sources, and ecological effects likely to occur in each of the assessment endpoints. Shown within the conceptual model are possible measures to evaluate response. Second-level models focus on particular assessment endpoints and show multiple stressors, potential exposure pathways and expected ecological responses.

2.3.1 Watershed Conceptual Model

The watershed-level conceptual model diagram illustrates connections among sources of stressors, stressors, effects, and assessment endpoints in the Waquoit Bay watershed. The diagram is organized around system stressors. Each stressor has a coded line type that illustrates a pathway connecting its sources to effects and endpoints. Each of the components of the model is represented by a different figure to aid interpretation (see key). This is a broad-based model that provides a framework for the risk assessment and an overview of ecosystem processes. The diagram shows only stressors and effects thought to occur in the Waquoit Bay watershed. It does not show the relative importance or magnitude of the stressors or effects. More detailed conceptual models were developed to evaluate multiple stressor effects and exposure pathways for specific assessment endpoints. These were generated as a result of detailed risk hypothesis development (see Section 2.3.2).

Key to Models:

Figure	Component	Figure	Component
Rectangle	Source of Stressor	Ellipse	Stressor
Double-line diamond	Primary ecological effect	Diamond	Secondary ecological effect
Parallelogram	Measurement	Octagon	Assessment endpoint

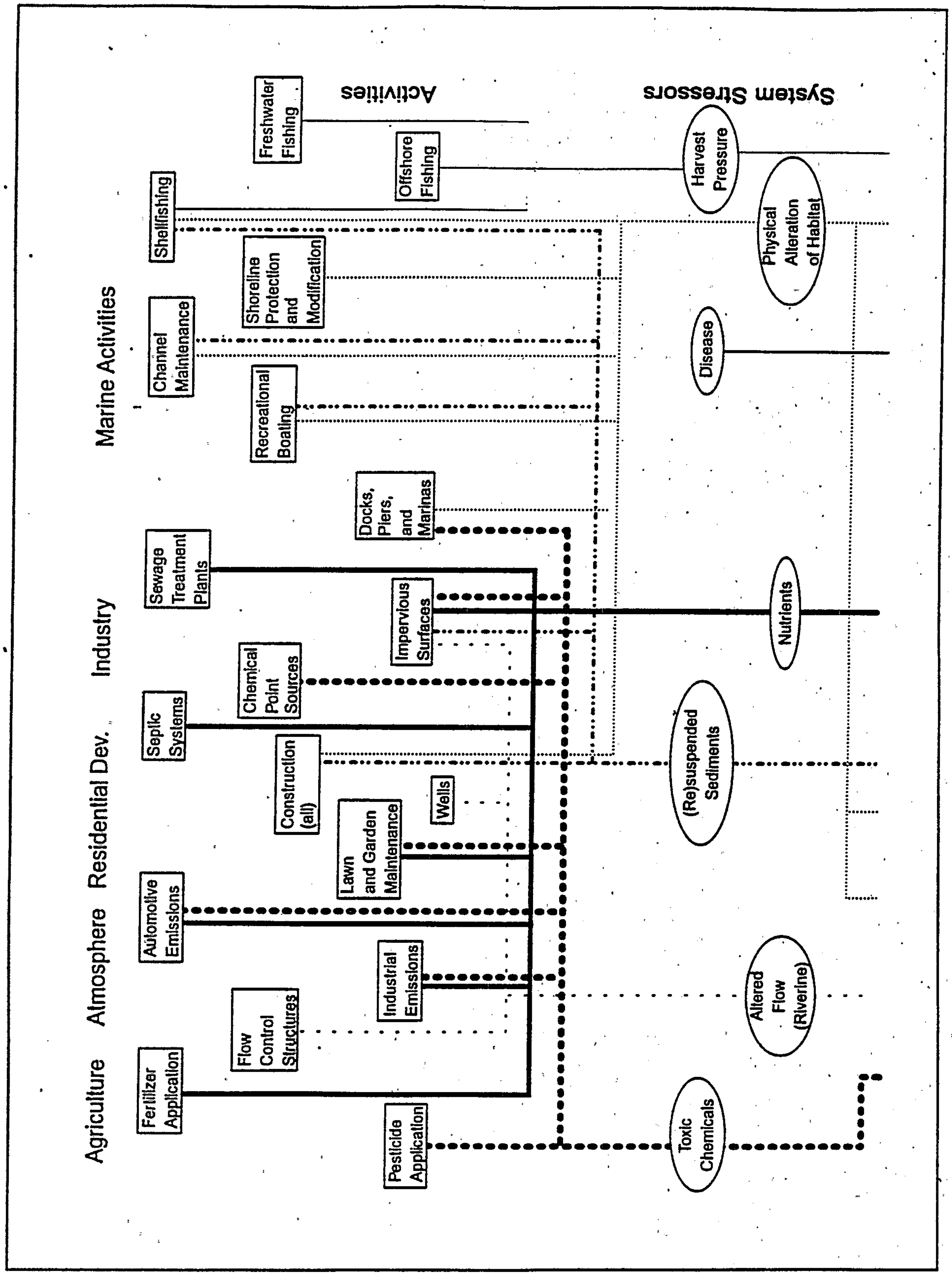

Figure 2. Waquoit Bay watershed conceptual model.

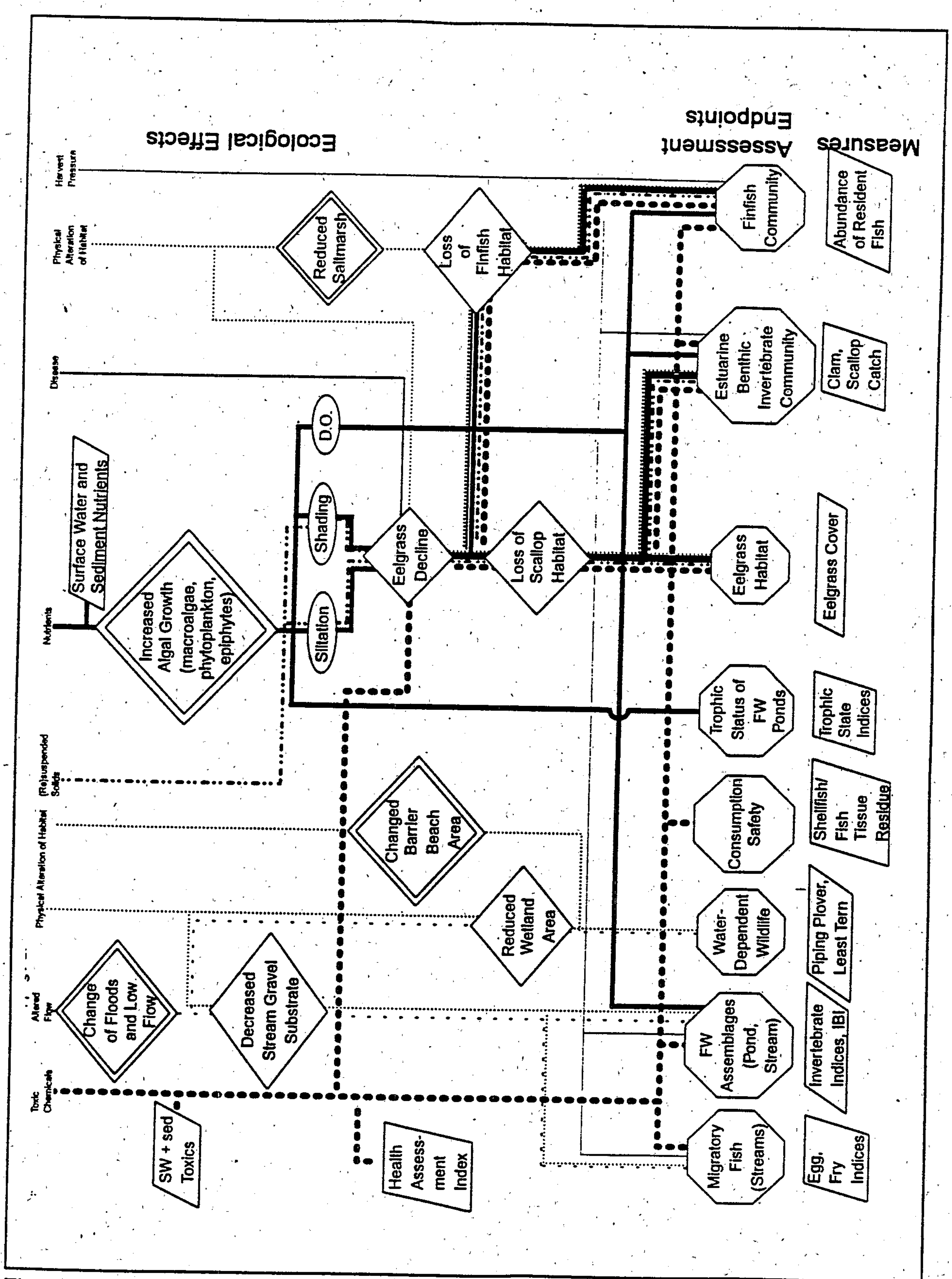

Figure 2. Waquoit Bay watershed conceptual model (continued).

Shown at the top of the model are five major human activities (agriculture, atmospheric deposition, residential development, industry, and marine activities). Within each of these major activities are one or more specific activities that serve as sources of stress in the watershed. For example, residential development results in housing and road construction, installation of septic systems, installation and maintenance of lawns and gardens, and construction of wells.

For each activity or source identified there are potentially one or more stressors that might exist in the watershed system. For example, nutrients serve as one major system stressor in Waquoit. However, sources of nutrients in this system are many and include fertilizer application, automobiles, lawn and garden maintenance, septic systems, impervious surfaces, and sewage treatment plants. The next level in the diagram shows predicted and observed ecological effects believed to result from exposure of the ecosystem to stressors. Represented here are several cascading effects. For example, nutrients can lead to algal growth, which contributes to increased chlorophyll in ponds and siltation, shading, and low dissolved oxygen in estuaries. These responses can lead to loss of eelgrass, suffocation of aquatic communities, habitat loss, and eutrophication with increased production of organic matter.

The potential adverse effects of one stressor can to affect one or many assessment endpoints. Nutrients, nitrogen or phosphorus can be traced to six assessment endpoints including freshwater benthic invertebrates, trophic status of ponds, pond fish community, eelgrass habitat, and estuarine benthic and finfish communities. In some cases indirect effects might not be represented here, but would be shown in the specific pathway conceptual models for a single assessment endpoint or a single stressor (e.g., although water-dependent wildlife are not connected to the nutrient matrix, nutrients affect the fish and invertebrate communities on which wildlife feed). Assessment endpoints for which appropriate data could prove difficult to obtain are identified later in the process but are represented in the conceptual model.

The watershed-level conceptual model diagram features seven stressors:

Toxic chemicals. Sources of toxic chemicals are agricultural pesticides, atmospheric deposition (metals and organics from automotive and industrial emissions), suburban lawn and garden chemicals, point sources (solvents and aviation/jet fuel derivatives in the MMR plumes), impervious surfaces (metals and hydrocarbons in road and roof runoff), and docks and marinas (metals and hydrocarbons from antifouling substances and boat motors). The toxic chemicals may affect aquatic animal life: migratory fish, pond fish, freshwater benthic invertebrates, estuarine benthic invertebrates, and estuarine fish.

Altered flow. Stream flow might be altered by flow control structures built for cranberry bogs, by groundwater depletion from well pumping, and by runoff from impervious surfaces. Altered flow can change the timing and magnitude of floods and low flow, as well as the amount of fish and invertebrate habitat available in streams, and riparian wetland area. Migratory fish, stream benthic invertebrates, and wetland-dependent wildlife that depend on these habitats might be adversely affected.

Resuspended sediments. Several watershed activities might contribute suspended sediment to the estuary or resuspend sediment in the bay. Activities that might contribute sediment include construction (all) and impervious surfaces (particulates in impervious runoff); activities that may resuspend sediment in the bay include construction of docks, boating, dredging, and shellfishing. Suspended sediment might contribute to siltation and shading of eelgrass.

Nutrients. Sources of nutrients include agricultural and suburban fertilizers, atmospheric deposition of nitrogen oxides, domestic septic systems, and wastewater treatment facilities. The primary effect of nutrient loading is growth of algae, principally phytoplankton in the ponds and macroalgae and periphyton in the estuary. Increased algal production increases the trophic state of the ponds and can contribute to hypoxia in both ponds and the estuary, with ultimate effects on invertebrates and fish. In the estuary, algal growth contributes to shading of eelgrass by macroalgae and periphyton, and eventual replacement of the eelgrass by algae. Loss of eelgrass may in turn cause cascading effects on estuarine invertebrate and fish communities. A more detailed conceptual model of eelgrass loss is shown in Figure 3 and a detailed conceptual model of the finfish community changes is shown in Figure 4.

Habitat alteration. Several activities in the watershed result in alteration of aquatic habitats. Construction activities might cause temporary or permanent habitat changes if the construction is in or near an aquatic habitat. Docks and piers are a permanent alteration of the aquatic habitat. Boating, dredging, and shellfishing might directly disturb eelgrass habitat and injure plants. Beach protection (jetties and groins) changes sediment transport and beach dynamics, potentially altering the barrier beach habitat. These alterations to streams, wetlands, barrier beaches, salt marshes, and eelgrass beds might adversely affect the organisms in those habitats.

Disease. Eelgrass wasting disease (*Labyrinthula*) is the only stressor in the conceptual model with no known anthropogenic source. It has a direct effect on eelgrass cover and hence has indirect effects on estuarine invertebrates and fish.

Harvest pressure. Harvest pressure includes fishing for freshwater fish, estuarine fish, anadromous fish, and shellfish and affects only those groups.

For the purpose of focusing on specific parts of this watershed, Figure 5 shows these pathways for the stream component, Figure 6 shows pathways for the pond component, and Figure 7 shows pathways for the estuarine component. Each of these pathways was created based on assumptions, or risk hypotheses, about how stressors are affecting or are expected to affect targeted assessment endpoints. They were derived from available information on the watershed gathered early in the problem formulation process and on a continuing basis, from ecological theory on how systems function, and from relationships established in other watersheds that are expected to be consistent from one geographic area to another where similar systems exist.

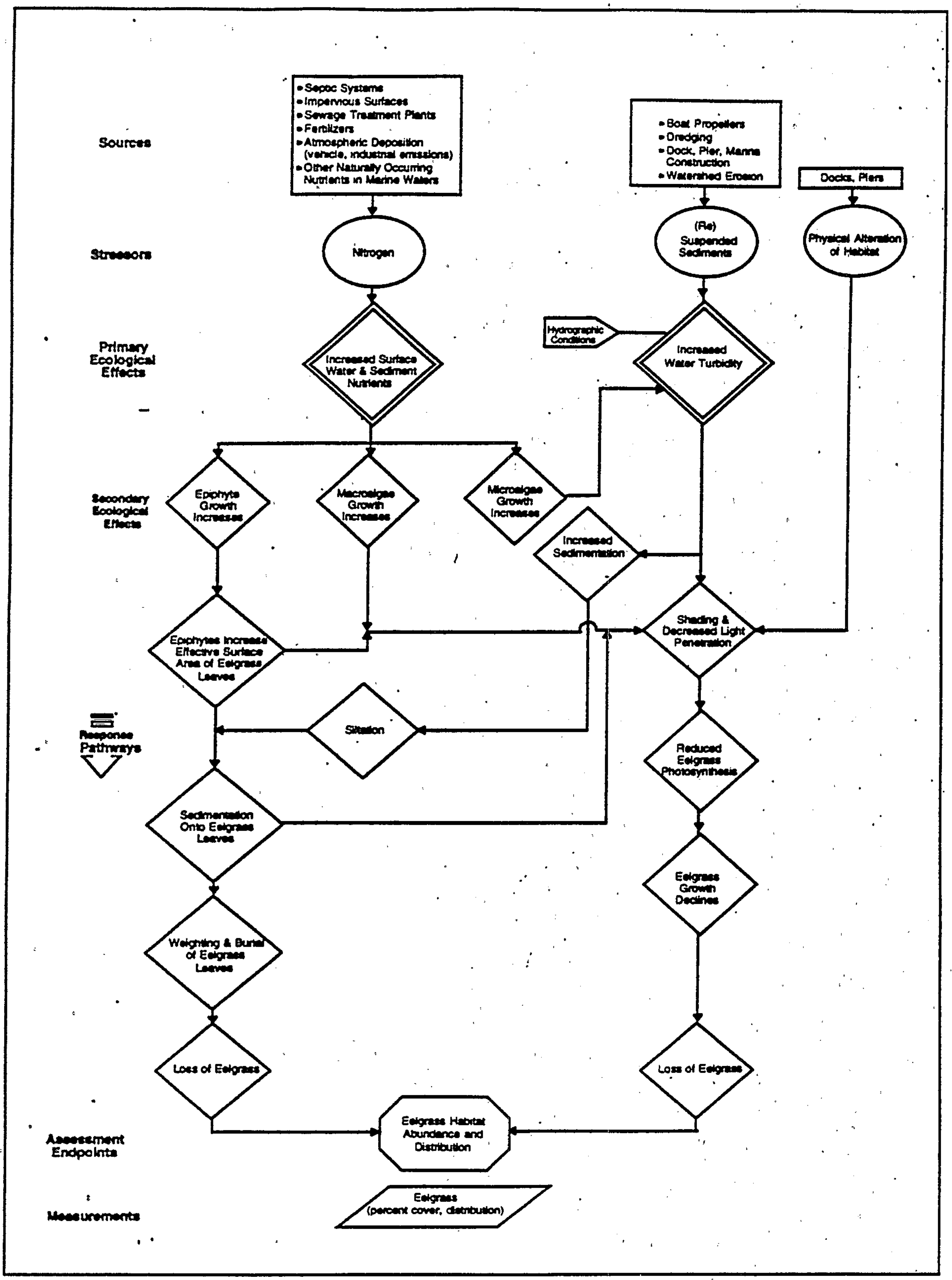

Figure 3. Eelgrass conceptual submodel.

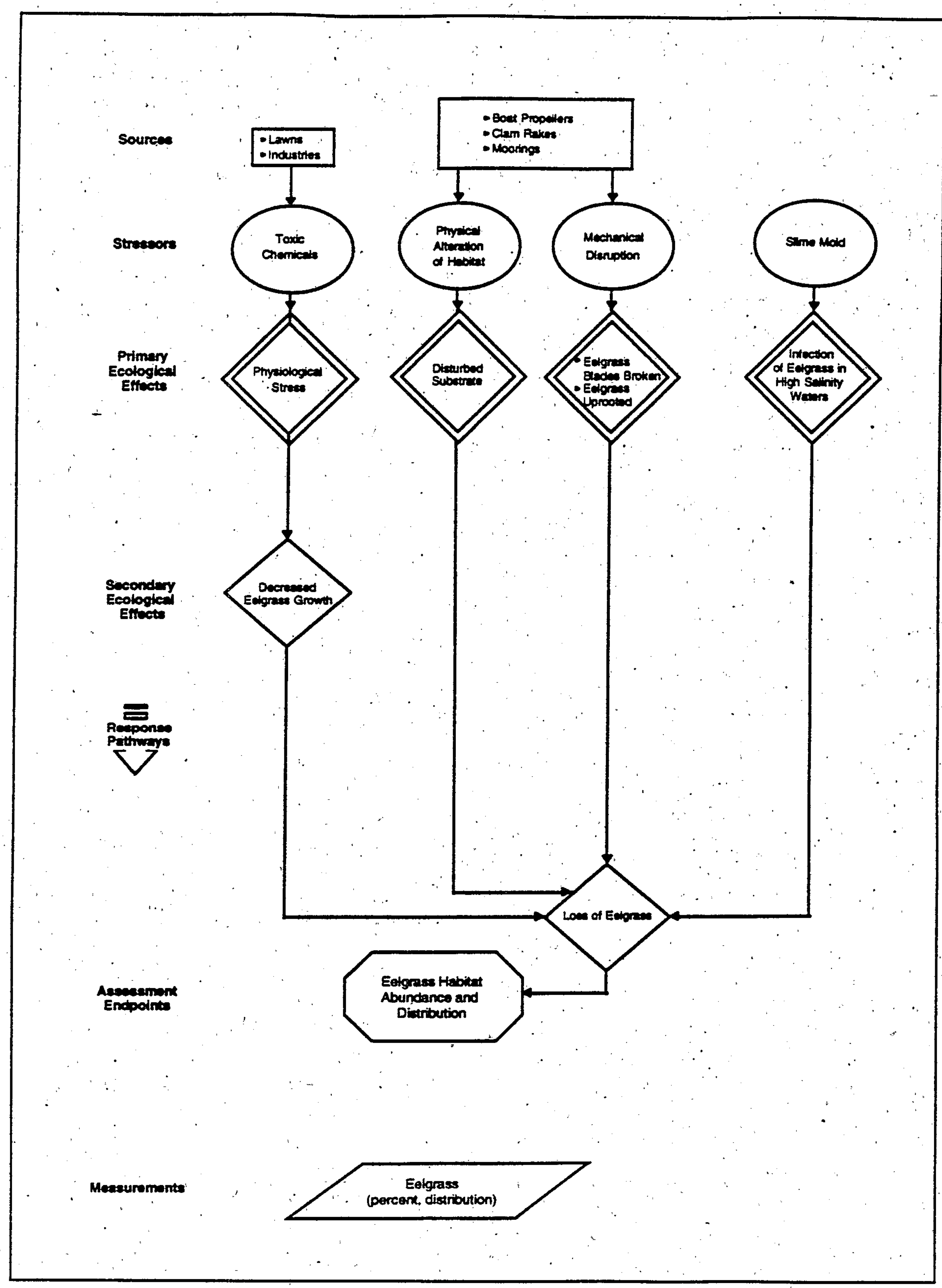

Figure 3. Eelgrass conceptual submodel (continued).

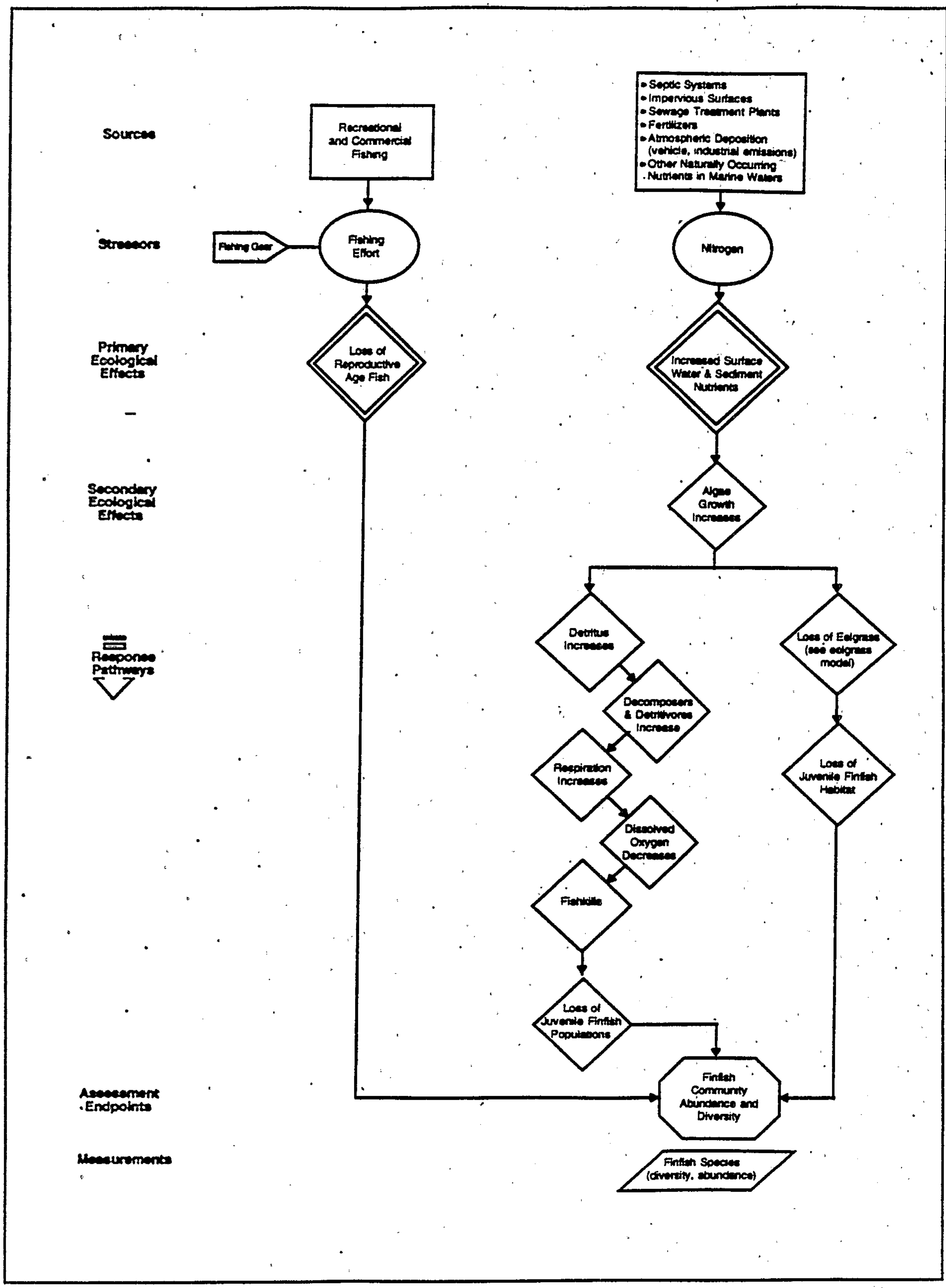

Figure 4. Finfish community conceptual submodel.

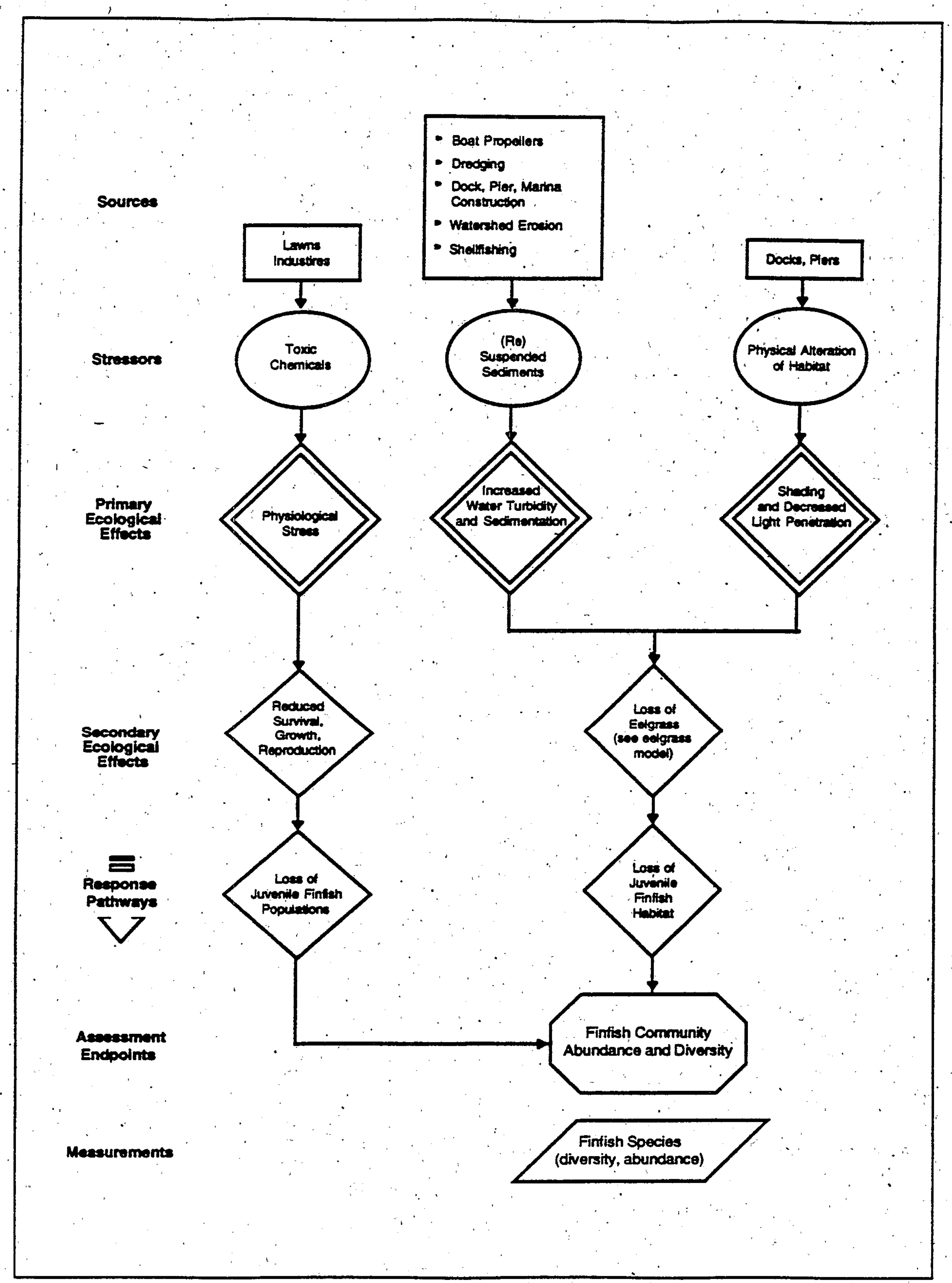

Figure 4. Finfish community conceptual sumodel.

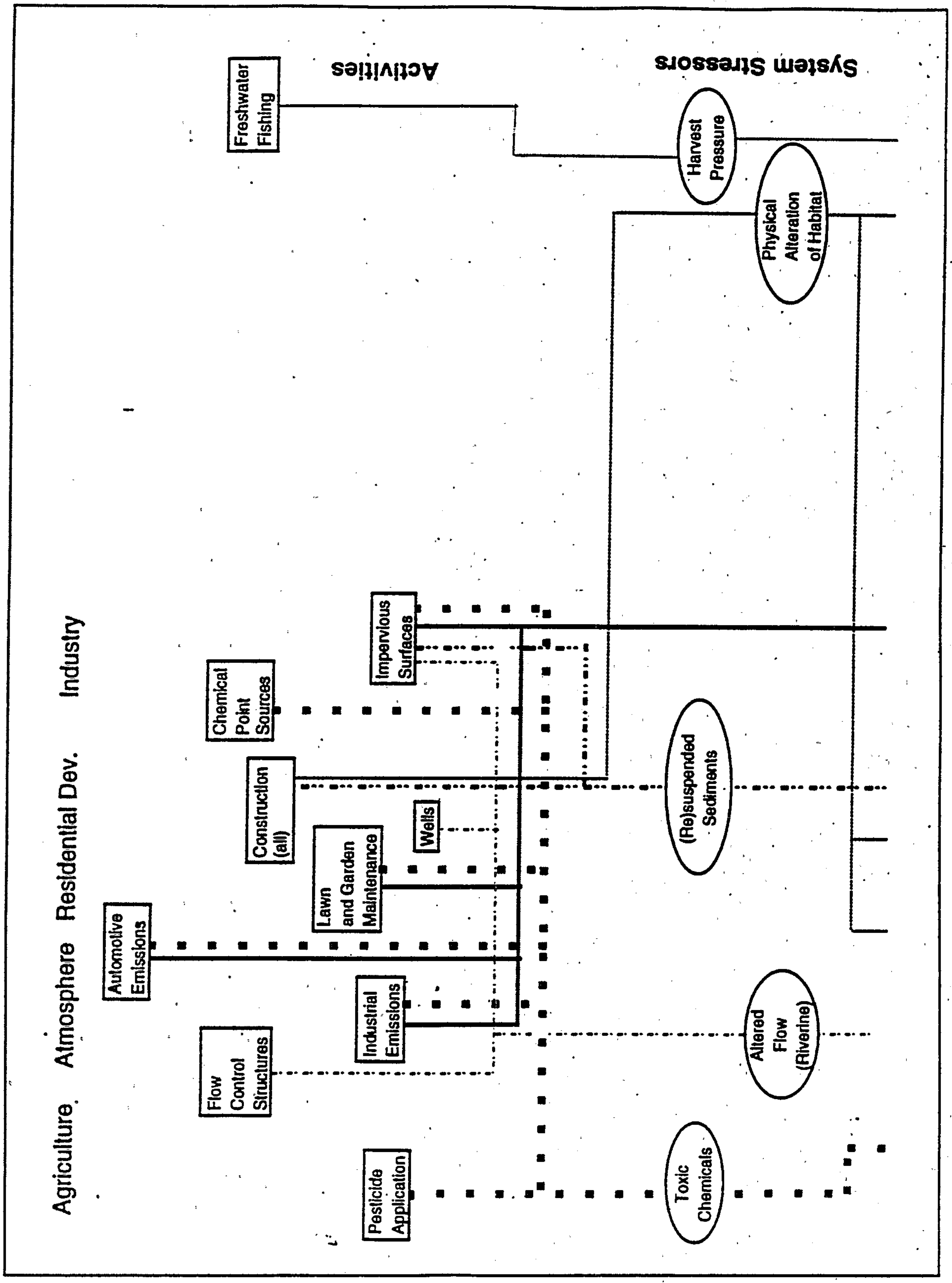

Figure 5. Waquoit Bay stream conceptual model.

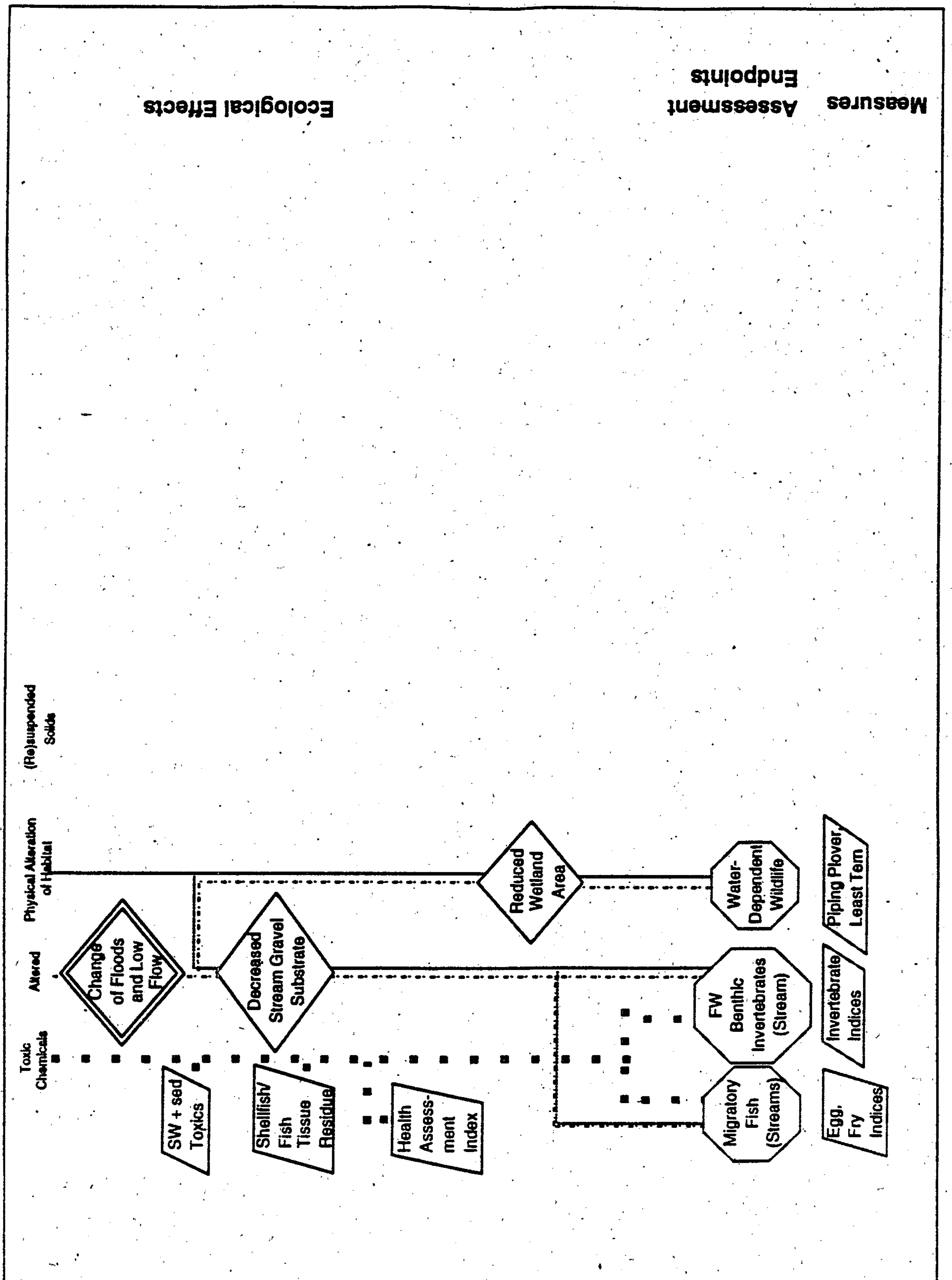

Figure 5. Waquoit Bay stream conceptual model (continued).

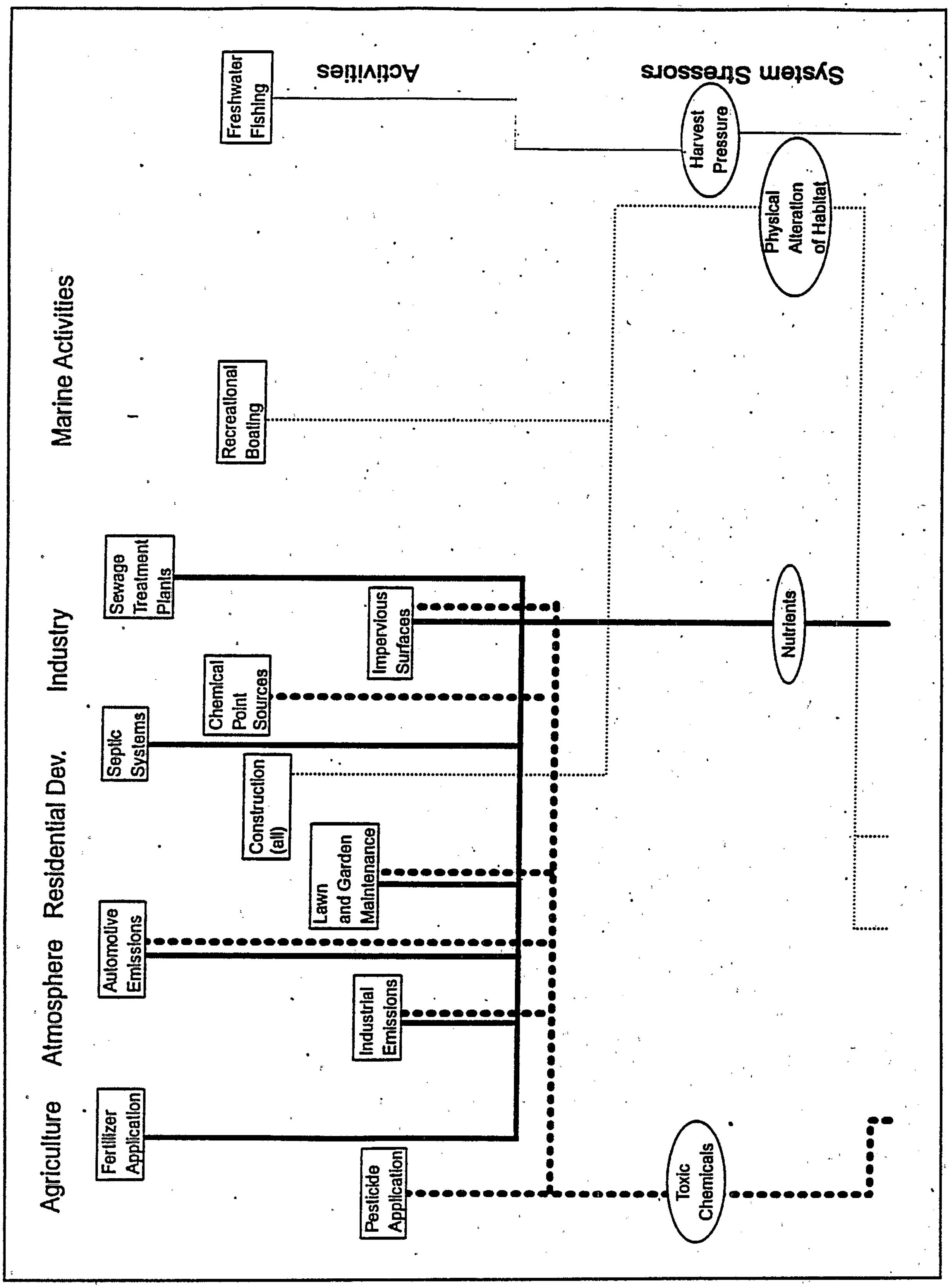

Figure 6. Waquoit Bay pond conceptual model.

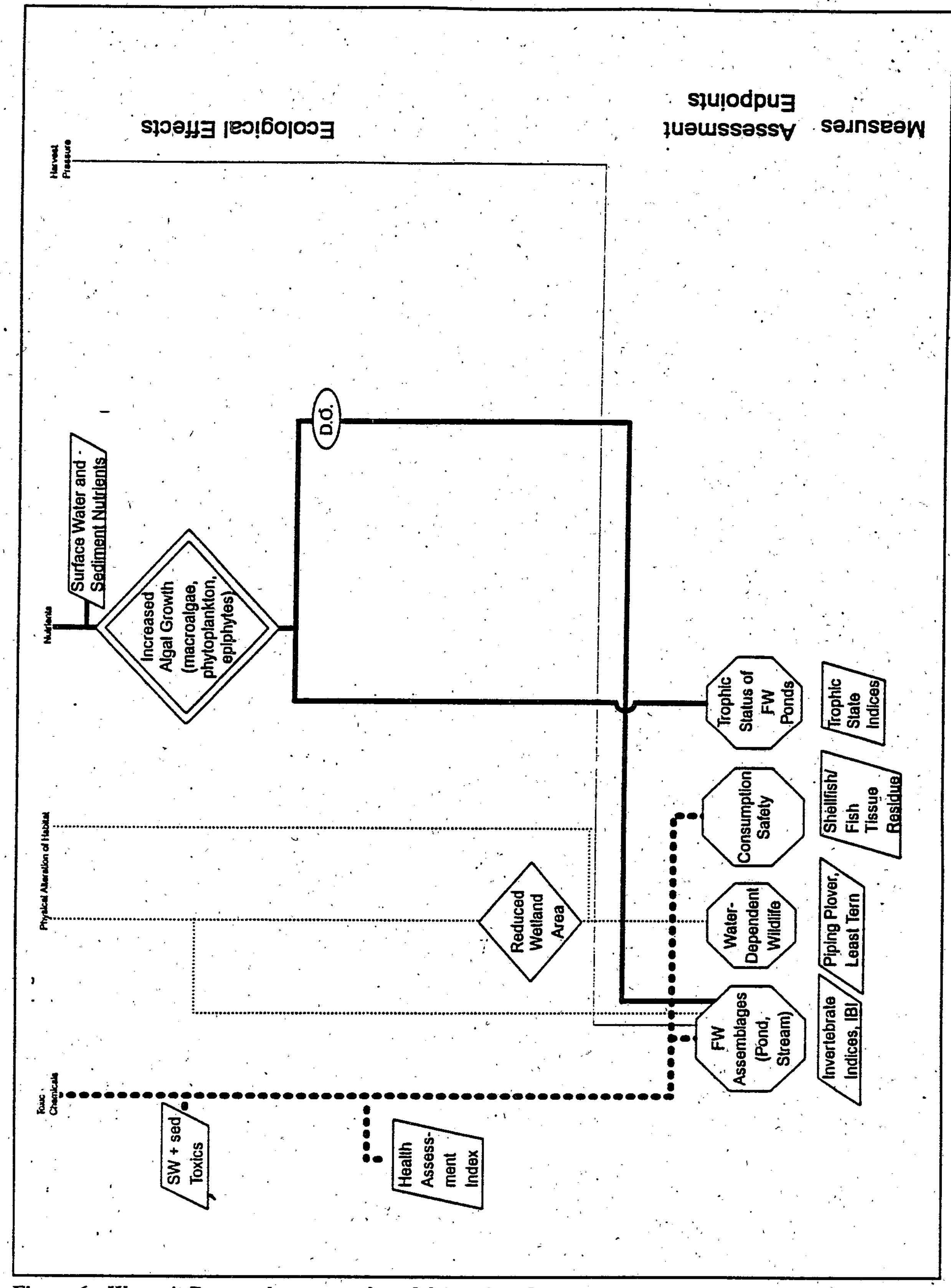

Figure 6. Waquoit Bay pond conceptual model (continued).

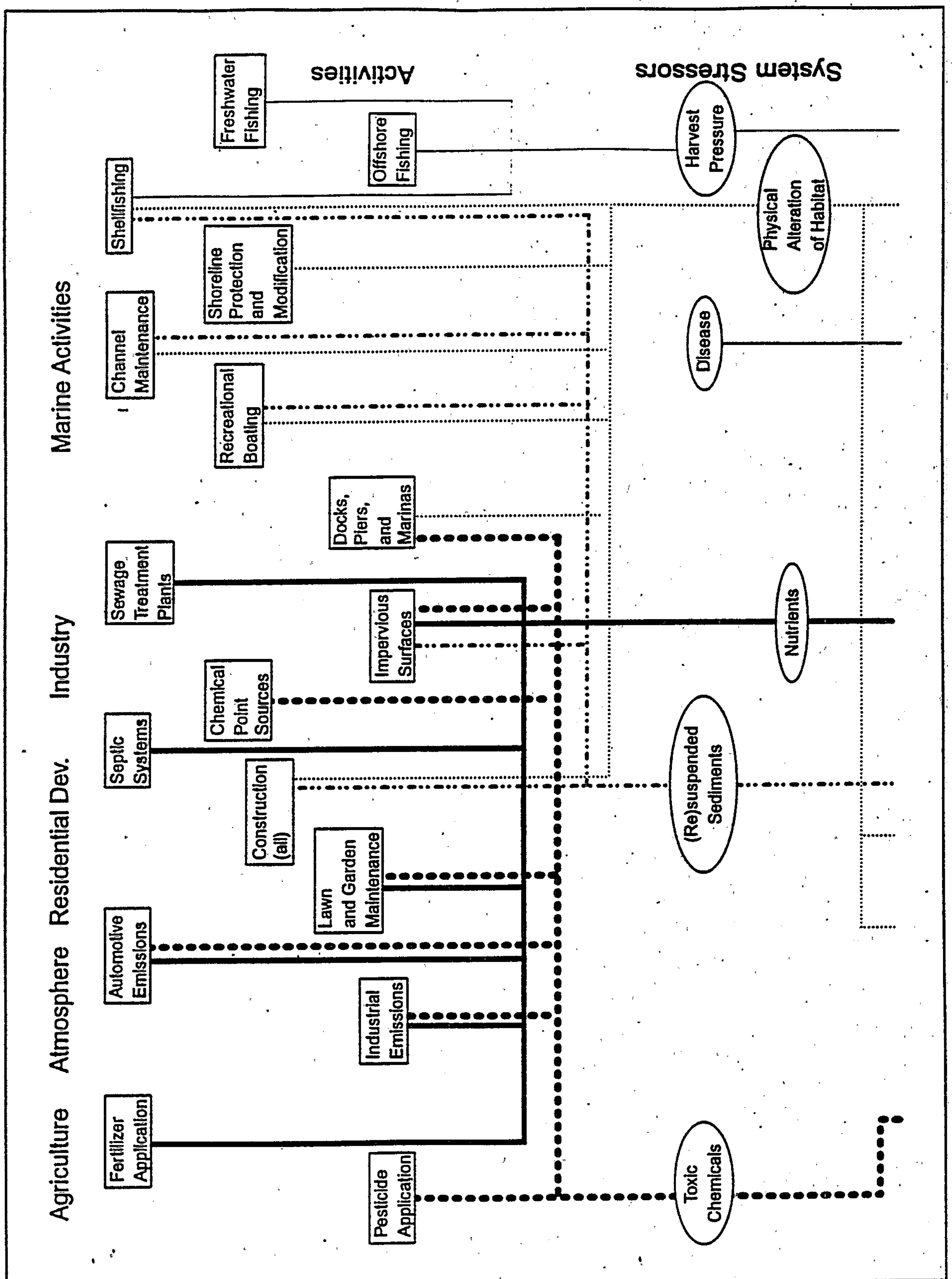

Figure 7. Waquoit Bay estuary conceptual model.

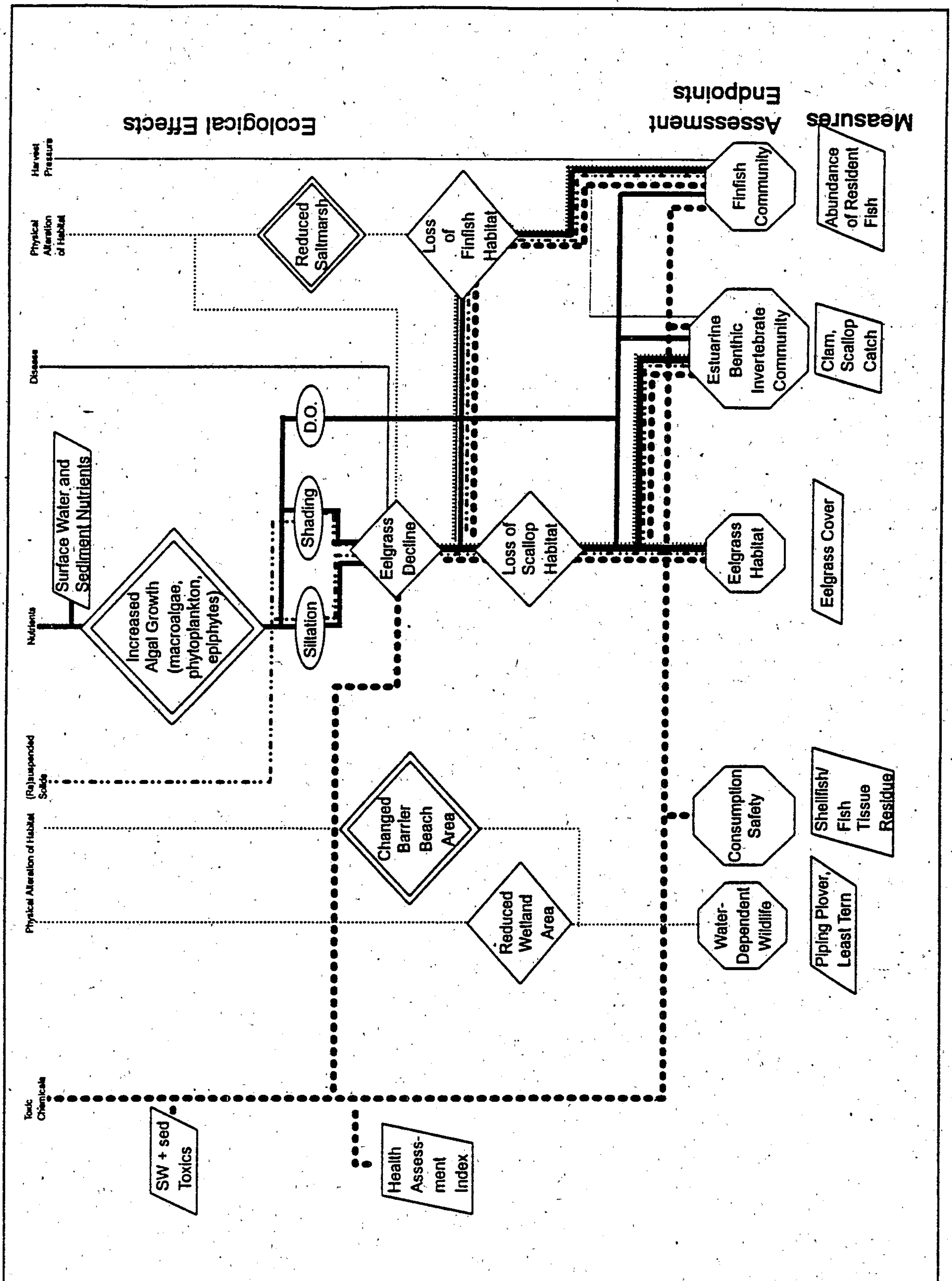

Figure 7. Waquoit Bay estuary conceptual model (continued).

2.3.2 Risk Hypothesis Development

The watershed conceptual model illustrates that each stressor might affect several endpoints and each endpoint might be influenced by several stressors. Since assessment endpoints provide the focus for this risk assessment and the intent of the assessment is to assess the risk of multiple stressors on a particular assessment endpoint, the following discussion on risk hypotheses is divided by endpoint. This approach provides the foundation for evaluating the cumulative and combined risk of more than one stressor. To understand how assessment endpoints are being affected by these stressors, however, it will be necessary to evaluate alternative exposure pathways of a stressor from different sources. Stressor pathways are evaluated through additional conceptual models.

The following risk hypotheses for eelgrass habitat abundance and distribution and finfish diversity and abundance are expressed as narratives about how assessment endpoints might become exposed and respond to one or more stressors. Background information that supports these hypotheses is available in Appendix E.

Development of conceptual models and risk hypotheses for the remaining six assessment endpoints is ongoing, but they are not ready for presentation at this time. The models developed for eelgrass and finfish provide a basis for determining how best to present information and develop the process. The conceptual models represent considerable information, but in many cases data are not available at this time to conduct an evaluation of posed hypotheses and predictions for these two endpoints. They are presented to allow managers and scientists in the watershed to consider potential research that will provide the basis for pursuing a more complete risk assessment. Further analyses of available data will allow the Team to refine hypotheses for the these and the other endpoints.

Eelgrass Habitat Abundance and Distribution: Risk Hypotheses and Conceptual Models.

The conceptual models and risk hypotheses for the eelgrass habitat abundance and distribution assessment endpoint include sources and stressors, cascading ecological effects, and response pathways. Eelgrass habitat is the common assessment endpoint for each of the source-to-response pathways represented in the model. Common measures (eelgrass habitat cover and extent) apply to each pathway. These measures are depicted outside the direct source-to-assessment endpoint pathways because they represent the result of ecological response rather than a direct measure of the response or attributes of the response pathways.

The following discussion is separated into two parts. The first provides predictive hypotheses about the effects of primary stressors depicted in the watershed conceptual model (Figure 2). These hypotheses and predictions are then followed by a descriptive conceptual model and hypotheses on the multiple pathways for loss of eelgrass from the variety of sources of these stressors and source-to-response pathways. Each of these pathways is illustrated in the eelgrass habitat conceptual submodel (Figure 3).

Stressor Hypotheses

The watershed conceptual model (Figure 2) contains five primary stressors for eelgrass: nutrients, sediments, physical alteration of habitat, toxics, and disease. Based on conclusions drawn from available information, multiple stressor effects have caused eelgrass to decline over the last 40 years. Each stressor has multiple sources. Reduction of one stressor or source is not likely to be sufficient for reestablishing eelgrass in the bay, although nutrient reduction is a necessary prerequisite.

Nutrients. Increased nitrogen loading in estuarine waters causes shading from excess growth of macroalgae, phytoplankton, and epiphytes. Historical and steady state inputs of nitrogen to ground water will continue to influence algal growth for up to 100 years. Additional development in the watershed will add to this nitrogen loading. Light attenuation in shallow estuaries might not be great enough to eliminate eelgrass altogether, but continuing inputs of nitrogen from current activities will prevent eelgrass recovery. Sub-bays with the greatest nutrient loads will have more macroalgae and less eelgrass. Those sub-bays with less nutrient loading will have less macroalgae and more eelgrass.

Suspended Sediments. Shading from resuspended sediments caused by physical disruption of bottom sediments results in decreased growth and the death of eelgrass plants.

Physical Alteration of Habitat. Available habitat for eelgrass has changed and will continue to change because of (1) loss of appropriate habitat from dock construction; (2) mechanical disruption from clam digging, boat props, and moorings, which cut eelgrass blades or uproot and kill eelgrass plants; and (3) subdivision of the meadow as a result of eelgrass death caused by mechanical disruption, disrupting community integrity and altering meadow composition.

Toxics. Toxics cause physiological stress on eelgrass plants, leading to slow growth. This could exacerbate effects from other stressors.

Disease. Slime mold acts synergistically with reduced light to decrease eelgrass growth, and water currents transport infected eelgrass blades, broken by physical disruption, to new areas.

Predictions:

- The replacement of eelgrass beds with fast-growing macroalgae will continue unless the amount of nitrogen entering the bay is reduced. Reestablishment of eelgrass will require reduction of nutrients.
- Reestablishment of eelgrass from reduced nutrient loading will occur only over a long time period to account for the time travel of nutrient laden ground water to the Bay.
- Reduction of nitrogen is a necessary but not sufficient requirement for eelgrass re-establishment. Habitat alteration from physical disruption will need to be reduced or confined to specific areas to allow reestablishment.
- The co-occurrence of wasting disease, toxics, and reduced water clarity might result in the complete elimination of eelgrass from the Waquoit Bay system. Complete elimination means that replanting might be the only means of reestablishing eelgrass meadows.

Conceptual Model

The primary stressors have multiple sources. The opportunity to reduce these sources of stressors are of primary management concern. The hypotheses below describe the eelgrass specific conceptual model to illustrate the multiple ways eelgrass can be lost from this system and to provide insights on where management action is most feasible. This discussion provides the basis for the conceptual model diagram shown in Figure 3.

Disease. The marine slime mold, *Labyrinthula*, causes "wasting disease." It is opportunitistic and likely to cause infection in stressed populations in more saline waters. The infection of eelgrass located in higher-salinity areas of Waquoit Bay leads directly to loss of eelgrass by death of infected individuals. Exposure pathways for the disease are not known; however, salinity influences infection such that eelgrass in areas of lower salinity is less likely to be infected. These areas are important for reestablishment.

Nutrients. Nitrogen is the primary nutrient of concern in the estuary. Nitrogen potentially enters the bay through multiple pathways including ground water discharge, air deposition, point source discharges, and impervious surface run-off. Exposure pathway analysis by Valiela et al. (1992) suggests that the principal pathway is via groundwater from septic system inputs (Appendix E, Figure E-6). The resulting increase in surface water and sediment nitrogen concentrations leads to increased growth of epiphytes, macroalgae, and microalgae. Epiphyte growth on eelgrass leaves decrease light availability by shading and increases leaf effective surface area, causing possible weighting and burial of eelgrass from increased siltation on leaves. Increased growth of macroalgal mats leads to direct shading of eelgrass and decreased light penetration. Phytoplankton growth increases water turbidity, decreasing light penetration to eelgrass. Algal growth also contributes to increased organic sediment, which might be resuspended by physical disruption (below) and contains a reserve of nutrients.

Construction and Recreational Activities. Boat propellers impinging on bottom sediments; dredging; construction of docks, piers and marinas; clam raking; mooring; and erosion in the watershed cause increased suspended sediments or resuspension of bottom sediments. Hydrographic conditions (e.g., wave amplitude, frequency, and direction; current velocity) act as forcing functions that can increase water turbidity. Turbidity increases shading and decreases light penetration. This leads to reduced eelgrass photosynthesis, growth decline, and death of eelgrass. It also causes siltation onto eelgrass leaves, compounding the effect of epiphyte growth discussed in the previous pathway.

Docks and Piers. Docks directly block light and reduce available habitat for eelgrass, leading to reduced eelgrass photosynthesis and loss of shaded eelgrass. Docks and piers also provide the basis for increased boat traffic, which leads to disturbance of sediments and increased turbidity in areas around the docks and piers. Great River, a tributary in the Waquoit Bay watershed, will show a loss of eelgrass in correlation with increased dock building.

Lawn Care, Agricultural, and Industrial Activities. Care of residential and commercial property lawns, agricultural activities (e.g., cranberry bogs), and industrial activities (e.g., MMR) in the watershed are a source of a variety of toxic chemicals. These may cause physiological stress in eelgrass, leading to reduced growth and death of eelgrass plants. Exposure pathways and effects from these sources of potential stress are little known.

Boat Propellers, Clam Rakes, Moorings. Boat propellers, clam rakes, and moorings directly disrupt bottom sediments, causing physical alteration of habitat and mechanical destruction of eelgrass blades, resulting in death or stress to the plant. Repeated activities without sufficient recovery time will result in decline in eelgrass beds because of direct loss of plants, and from the creation of small patches, increasing vulnerability to other stressors (e.g., storm events). Boating activities that churn up bottom sediments will increase the amount of suspended sediments, increasing turbidity and decreasing light penetration to eelgrass beds. Epiphytes growing on eelgrass blades provide good depositional surfaces for suspended solids and can weigh down the eelgrass blades causing them to sink to the bottom where they die from insufficient light or suffocation (Short, 1989).

Resident Estuarine Finfish Diversity and Abundance: Risk Hypotheses and Conceptual Model

The conceptual models and risk hypotheses for the resident finfish diversity and abundance assessment endpoint include sources and stressors, cascading ecological effects, and response pathways. Resident finfish is the common assessment endpoint for each of the source-to-response pathways represented in the model. Common measures (diversity and abundance) apply to each pathway. These measures are depicted outside the direct source-to-assessment endpoint pathways because they represent the result of ecological response rather than a direct measure of the response or attributes of the response pathways.

The following discussion describes the principal stressors represented in the watershed conceptual model (Figure 2) and specific predictions to consider. This is followed by the presentation of the finfish conceptual model and descriptive hypotheses about relationships depicted in the model.

Stressor Hypotheses

Multiple stressor effects are resulting in lowered reproductive success of adult resident finfish, as well as lower survival of eggs and juvenile finfish. Each stressor has multiple sources. Determining the relative contribution of these stressors will be important for setting management priorities.

Nutrients. Increased nitrogen loads alter finfish diversity and abundance through excessive macroalgal growth, which results in (1) loss of eelgrass habitat for breeding, feeding, and hiding and (2) hypoxic and anoxic conditions that result in physiological stress, exposure to predation, and suffocation.

Suspended Sediments. Increased sediment in the water column alters finfish breeding, feeding, and hiding habitat by (1) reducing growth of eelgrass, (2) covering available habitat, (3) smothering eggs and juveniles, and (4) reducing feeding success of visual predators.

Physical Alteration of Habitat. Development of land adjacent to prime finfish nursery habitats causes a direct loss of available nursery areas and contributes to sediment and nutrient loading in the vicinity of nursery areas. Direct physical alteration of nursery areas from dredging, boat prop disturbance, and changes in flow patterns from inlet changes and armoring of coasts alters quality or removes habitat from potential use.

Toxic Chemicals. Multiple sources of toxic chemicals from pesticide application, air pollution, lawn maintenance, point source discharges, nonpoint runoff and chemicals used on docks and boats combine to alter survival and reproduction of juvenile finfish. Stress from hypoxic and anoxic conditions exacerbates the effects of toxicity.

Harvest Pressure. Recreational fishing removes reproductive adults from the population of resident finfish. Although offshore fishing alters the available adult stock returning to Waquoit Bay, this reflects regional impacts and no hypotheses are pursued for this portion of the finfish community.

Predictions:

- Loss of eelgrass habitat (from multiple stressors) will favor species associated with open-water, nonvegetated habitats such as Atlantic silverside, adult summer flounder, and winter flounder as well as rock crabs and green crabs, over those species associated with vegetated habitats such as tidewater silverside, juvenile summer flounder, grass shrimp, rainwater killifish, juvenile tautog, fourspine stickleback, and striped killifish.

- Loss of eelgrass habitat and projected changes in the functional aspects of the finfish community will result in (1) increase in omnivores; (2) decline in top carnivores; (3); shift from benthic to pelagic habitats; (4) decline in total number of species, estuarine spawner species and estuarine resident species; (5) increase in disease incidence and morphological abnormalities; (6) decrease in eelgrass habitat quality prior to physical habitat loss; (7) increase in dominance of eutrophic tolerant species where dominance represents the number of species accounting for 90 percent of the total numbers or biomass; and (8) higher fish density and biomass (abundance) in medium-quality compared to low-quality habitats (Deegan et al., 1993).

- Increasing contaminant inputs from recreational activities and future toxicity from contaminated ground water plumes from MMR will increase abundance of tolerant species and increase incidence of finfish malformations and disease.

- Anoxia and hypoxia will slow the growth, maturation, and reproduction of sensitive finfish (e.g., Atlantic silversides, juvenile winter flounder, and juvenile tautogs versus mummichogs).

Conceptual Model

The primary stressors have multiple sources. The opportunity to reduce these sources of stressors are of primary management concern. The hypotheses below describe the finfish conceptual model to illustrate the multiple ways finfish diversity and abundance are likely to change and to provide insights on where management action is most feasible. This discussion provides the basis for the conceptual submodel diagram shown in Figure 4.

Recreational and Commercial Fishing. Estuarine and offshore fishing remove reproductive aged fish from the population. This mortality will exacerbate other losses to adults, juveniles and eggs from other stressors and can change the dynamics of the finfish community resulting in shifts in competition, feeding patterns and other behaviors.

Nutrient Loading. Nutrient loading increases algal production in the estuary. Increased production leads to increased organic matter loads and increased respirational oxygen demand, resulting in periodic oxygen stress and occasional fish kills on warm, cloudy, calm days in summer, when the bay may stratify. Nutrient loading also might lead to loss of eelgrass (see eelgrass conceptual submodel Figure 3). Eelgrass beds are a nursery area for juvenile finfish; hence, loss of eelgrass may lead to declines in fish recruitment and fish populations.

Toxic Chemicals. Toxic chemicals from lawns, agriculture, impervious surfaces and the MMR plumes might cause direct morbidity and mortality of resident finfish in all age classes although some age classes could be more susceptible. Toxic chemicals also might lead to loss of eelgrass (see eelgrass conceptual submodel Figure 3). Eelgrass beds are a nursery area for juvenile finfish; hence, loss of eelgrass might lead to declines in fish recruitment and eelgrass dependent fish populations.

Sediments, Physical Alteration and Disruption. These stressors all can lead to loss of eelgrass (see eelgrass conceptual model Figure 3). Eelgrass beds are a nursery area for juvenile finfish; hence, loss of eelgrass can lead to declines in fish recruitment and fish populations. These stressors might also lead to loss of salt marshes through direct alteration. Salt marshes are spawning and nursery areas for several estuarine finfish and forage fish, hence, loss of salt marshes might lead to declines in fish recruitment and fish populations.

2.4 Analysis Plan

The large number of assessment endpoints identified in this risk assessment required a preliminary evaluation of overlap among endpoints. A comparative risk analysis was used to help define which stressors, assessment endpoints, and relationships should be examined further. To do this preliminary analysis, stressors were ranked in terms of potential risk to all resources in the watershed. The following comparative risk analysis was conducted by the risk assessment team and is considered preliminary. It requires additional verification and peer review by scientists in the watershed.

The comparative risk analysis identified nutrient loading as the single most important stressor in aquatic habitats of the watershed. Accordingly, the team decided to focus subsequent analysis on nitrogen loading and eelgrass in the estuarine portion of the system. This analysis is twofold: 1) development of empirical models to predict response of eelgrass habitat to nitrogen loading; and 2) development of models to predict nitrogen loading (from all sources) in the future as suburban development proceeds and as management actions are implemented.

Following discussion of the development of predictive models, the remainder of the analysis plan discusses potential analyses that might be conducted to examine risks from other stressors that are not the focus of this initial effort.

2.4.1 Comparative Risk Analysis

To conduct a comparative risk analysis, a process called "fuzzy set," which is based on best professional judgment (Harris et al., 1994; Wenger and Rong, 1987), was used. This approach was applied to each endpoint and stressor. The fuzzy set approach is a decision analysis method for ranking alternatives according to multiple criteria. Applied to ecological risk assessment (Wenger and Rong, 1987; Harris et al., 1994), stressors are the alternatives and the assessment endpoints are the criteria. The analysis then ranks the stressors in order of greatest overall contribution of risk to the endpoints.

A preliminary impact matrix for the Waquoit Bay watershed, derived from the conceptual model, is shown in Table 5. Each column represents a single endpoint, and each row a single stressor from the conceptual model. Every connection in the conceptual model from a stressor to an assessment endpoint is represented by a non-zero cell in the effect matrix (Table 5). Estuarine and freshwater elements are combined in this matrix, as they are in the conceptual model. Each cell contains the effect of a stressor on an endpoint, on an ordinal scale from 0 (no effect) to 3 (severe effect)

(Harris et al., 1994). For example, the effect of nutrients on eelgrass habitat is given a 3 (severe, indirect effect), but the effect of physical alteration on eelgrass habitat is given a 1 (slight effect) (Table 5). The effect of toxic substances on pond trophic state is given a 0, because toxic substances in the watershed are not thought to affect pond trophic state (no pathway in the conceptual model). Values in Table 5 were obtained by consensus among the team, but are preliminary and have not yet been reviewed by other scientists.

Table 5. Hypothesized effects matrix; each cell represents relative effect of a stressor on an endpoint.

Stressors	Migratory fish	Freshwater inverte-brates	Water-dependent Wildlife	Pond trophic status	Contami-nation	Eelgrass habitat	Estuarine inverte-brates	Estuarine fish
Toxic chemicals	1	1	0	0	2	0	1	1
Altered flow	2	2	2	0	0	0	0	0
Suspended sediments	0	0	0	0	0	2	1	1
Nutrients	0	1	0	3	2	3	2	2
Physical alteration	2	1	1	0	0	1	1	1
Harvest Pressure	1	0	0	0	0	0	1	2
Disease	0	0	0	0	0	2	1	1

Rankings were obtained by the difference method, as explained in Wenger and Rong (1987) and Harris et al. (1994). The effects of each stressor j on endpoint k are subtracted from the effects of stressor i :

$$D_k(i,j) = x_{ik} - x_{jk} \quad \text{(Harris et al. 1994).}$$

The matrix $R = (_{ij})$ is an m x m matrix of the sums of the above differences for all endpoints k:

$$r_{ij} = SD_k(i,j), \quad i,j = 1, 2, \ldots, m \quad \text{(Harris et al., 1994).}$$

See Wenger and Rong (1987) for further formulas. The row sums of matrix R were used for ranking the stressors; the largest row sum was the dominant stressor (Table 5, Base Case). Using the impacts of Table 5, nutrients were ranked first, followed by physical alteration, altered flow toxic chemicals, and finally harvest pressure, suspended sediments and disease (Table 6).

Stressors can be weighted by the persistence of the stressors if their input is removed. Persistence of stressors was ranked on a scale of 1 to 5, where 1 represents almost no persistence, and 5 is an effect that lasts indefinitely (Table 7). Altered flow and physical alteration received a persistence score of 5 because they are permanent changes that do not reverse themselves. Toxic chemicals and nutrients received a persistence score of 3 because of the time delay in ground water travel to reach water bodies. Thus, if sources of either toxics or nutrients were stopped, substances remaining in the ground water would still affect water bodies for some time. Suspended sediments, harvest pressure, and disease received a score of 1 because they are all relatively nonpersistent; i.e, if fishing is stopped, there is no "residual" harvest pressure. Results of the weighting are also in Table 6 (weighted column). When weighted, the stressors tied previously for third place (altered flow, toxics) differentiated into third and fourth place (Table 6).

Table 6. Stressor ranks under three scenarios.

Stressors	Base Case	Weighted Stressors	Weighted with Stressor interaction
Nutrients	1	1	1
Physical alteration	2	2	2
Altered flow	3	3	3
Toxic chemicals	3	4	4
Harvest pressure	4	5	5
Suspended sediments	4	5	5
Disease	4	5	5

Stressors may interact with one another by exacerbating other stressors (Harris et al., 1994). Interactions among the stressors are shown in Table 8. Both members of an interacting pair of stressors receive a score because both must be present for the interaction to work. Interaction scores were set at 1 because they are plausible, hypothesized relationships, with no information on their relative strength or actual existence. Nutrients can enhance the effects of both suspended sediments and disease by causing excess organic floc that can be resuspended, and shaded eelgrass may be more susceptible to disease. Excess organic floc contributes to sedimentation. Toxic chemicals may stress eelgrass plants so that they are more susceptible to disease. The resultant rankings reflecting both weighting and interaction (Table 6, rightmost column) were the same as the weighted scenario only.

Table 7. Relative persistence of stressors.

Stressor	Duration
Nutrients	3
Physical alteration	5
Altered flow	5
Toxic chemicals	3
Harvest pressure	1
Suspended sediments	1
Disease	1

Table 8. Interaction among stressors.

Stressor	Interaction
Nutrients	1
Physical alteration	0
Altered flow	0
Toxic chemicals	1
Harvest pressure	0
Suspended sediments	1
Disease	1

Ranks were very similar among the three models, showing that the hypothesized effects matrix (Table 5) was robust to changes in persistence and interaction. Nutrients were always ranked first; physical habitat alteration was always ranked second. Suspended sediments and disease were always ranked last. Altered riverine flow, and toxic chemicals, were tied in the middle in the unweighted scenario, but when weights were applied they differentiated from each other. The robustness of the rankings was due primarily to the number of endpoints affected by each stressor:

Nutrients and physical alteration each affected six endpoints, and nutrients had two strong effects on two assessment endpoints (eelgrass habitat and pond trophic status). The comparative risk analysis presented here must be regarded as preliminary because the effects matrix (Table 5) has not at this writing been reviewed and agreed to by experts and knowledgeable persons on ecological effects in estuaries. In the absence of quantitative data on the relative magnitudes of effects of the different stressors, expert consensus is required.

2.4.2 Development of a Regional Model of Eelgrass Response to Nutrient Loading

The comparative risk analysis, as well as prevailing scientific opinion prior to the comparative analysis, indicated that excess nutrient loading, particularly nitrogen, is the principal stressor affecting Waquoit Bay estuary, which prevents most of the management objectives from being met. More detailed analysis will identify and address critical gaps in the relationship between nutrient loading and assessment endpoints. This analysis will consist of two parts: determination of the predictive relationship between nutrient loading and eelgrass cover in estuaries of Cape Cod; and prediction of future nutrient loading to Waquoit Bay under various scenarios of construction and buildout.

Although it has been known for some time that nitrogen loading contributes to estuarine eutrophication and loss of SAV in Waquoit Bay and other estuaries of Cape Cod (e.g., Costa 1988; Valiela et al. 1992; D'Avanzo and Kremer, 1994), predictive relationships between nitrogen loading or nitrogen sources on the one hand, and the biological response of the estuary on the other have not been developed for estuaries such as Waquoit. The objective of this analysis will be to develop the link between estimates of modeled nitrogen loading and predicted ecological effects in the estuary.

The relationship has been examined within Waquoit Bay over time and among its subestuaries, but in each case sample size was too small for statistical inference and for estimation of uncertainty (n=5; Valiela et al., 1992). There is a clear correlation between population growth in the Waquoit Bay watershed, the decline of eelgrass, and the decline of scallops (Valiela et al., 1992). However, observations within the Bay and its subestuaries are a form of pseudoreplication because the observations, being from a single place, are not independent (Hurlbert, 1984). Extending the sample space to include similar embayments of Cape Cod would alleviate the pseudoreplication problem and would increase sample size to allow estimation of uncertainty.

Objectives

- Quantify the extent and cover of eelgrass historically and presently in Waquoit Bay and in other similar estuaries.

- Estimate nitrogen loading in Waquoit Bay and in other similar estuaries in the region.

- Develop an empirical model of the response of eelgrass cover (assessment endpoint) to estimated nitrogen loading (stressor) in Waquoit Bay and in other similar estuaries.

Submerged aquatic vegetation (SAV) is a sensitive indicator of eutrophication in estuaries (Dennison et al., 1993) and is easily monitored with aerial photography. As described in Section 2.2, eelgrass beds are preferred habitat of juvenile scallops, and are a nursery and feeding area for estuarine fish. Eelgrass beds can be identified and quantified from aerial images and can be distinguished from other SAV (e.g., *Ruppia*, *Codium*) and from macroalgae and bare sediment. For these reasons, eelgrass cover was selected as a measurement endpoint for eelgrass habitat, estuarine finfish habitat, and estuarine benthic invertebrate (including scallop) habitat.

Justification and approach. The analysis approach for the nutrient hypothesis will be to examine relationships between eelgrass cover and predicted nitrogen loading using a larger and more independent sample of similar estuaries throughout Cape Cod, Martha's Vineyard, and Nantucket. A similar approach was used to develop a predictive model for the estuaries of Buzzard's Bay (Costa, 1992). The Buzzard's Bay estuaries are open and well-flushed, unlike Waquoit Bay, which is isolated by a barrier beach and has only a narrow outlet to the sea. There are several other estuaries on Cape Cod, similar to Waquoit Bay, with limited tidal flushing, varying degrees of residential development, narrow inlets restricting water exchange with open water, and substantial ground water input from the sandy glacial moraines and till of the region.

The approach will be to develop one or more regression models of eelgrass cover in estuaries of Cape Cod and the islands. Eelgrass cover in each estuary, digitized from a series of aerial images, will be the response variable. The principal predictive variable will be nitrogen loading, estimated for each estuary from one of three extant N loading models (reviewed by Cadmus, 1995). An alternative model will use watershed land use directly as a predictive variable. Sources of nitrogen (residential septic systems, lawns, discharges) nearest an estuary are expected to have a proportionately greater effect on eutrophication and eelgrass cover than distant sources, due to attenuation of N in groundwater (Valiela et al., 1996) and due to greater travel time from the distant sources (Sham et al., 1995). This will be modeled by separating near sources from distant sources as predictive variables in a multiple regression model (see below).

The objective of this exercise is to develop predictive relationships between estimated nitrogen loadings and eelgrass cover in Cape Cod estuaries. The central assumption is that the estuaries behave similarly and that by altering nitrogen loading of a given estuary (i.e., Waquoit Bay) eelgrass will respond as predicted by the empirical model. This approach has been successful in management of eutrophication in lakes and has been successfully applied to the small estuaries of Buzzard's Bay, and to larger estuaries such as Tampa Bay (Tampa Bay NEP, 1995). Therefore, it should also be successful for the estuaries of the South Shore of Cape Cod.

Models for estimating nitrogen loading. There are currently three models (CCC, WBLMER, and BBNEP) of nitrogen loading for Cape Cod estuaries. Each predicts the total N loading from measured variables, including the amount and distribution of residential septic systems, impervious surfaces, lawns, natural vegetation, atmospheric deposition and other sources. The models differ in assumptions on N transformations in ground water and the fate of atmospheric N deposition on land, but all three result in substantially similar estimates of total N loading to the estuary (Cadmus, 1995). A fourth model (Sham et al., 1995) takes into account the time required for nutrient-laden groundwater to travel to surface waters, where it can contribute to eutrophication. Newly constructed septic systems and discharges may not contribute to nutrient loading for several decades, depending on the hydraulic travel time from the source to a surface water body (Sham et al., 1995). By analyzing construction dates of discharges and travel times, Sham and colleagues estimated that current loading to Waquoit Bay is approximately 70 percent of the ultimate loading from existing structures, and that 90 percent of the ultimate loading is reached in approximately 10 years (Sham et al., 1995).

The analysis here will take into account ground water travel time, as elucidated by Sham et al. The analysis used the CCC model as its base and also required a complete land parcel database for the Waquoit watershed, with date of construction for each parcel, as well as estimation of ground water flow velocities from the extensive well data in the Waquoit watershed. A similar analysis at the same level of detail for all watersheds in the model would be prohibitive. Such a level of detail is probably unnecessary because the three base models for N loading have an estimated uncertainty of 25 to 40 percent (M. Geist, personal communication). Given the uncertainty of the base models, it should be possible to develop coarser estimates of travel time and construction date and still be within the uncertainty limits of the base model.

Given the prediction that 90 percent of ultimate nitrogen loading is reached in 10 years (Sham et al., 1995), travel time can be approximated by estimating areas representing travel times of 0 to 5 years, 5 to 10 years, and greater than 10 years. On a map, these would appear as concentric bands around an estuary or parallel to a stream. A first-order approximation would be to estimate the distance traveled by ground water in 5 years (approximately 1 km in Sham et al., 1995) and apply that distance to all watersheds in the analysis. Land use and dates of construction can be estimated for each of the three travel bands from a GIS database, and one of the N loading models can then be applied to estimate total N from each of the three source areas.

Cape Cod Estuary characterization. Approximately 90 semi-enclosed estuaries and subestuaries are on the south shore of Cape Cod and the islands with a relatively narrow outlet to the sea or to another estuary. Some will prove to be inappropriate for a regional model (e.g., too small, too isolated, too open), but approximately 50 estuaries, might be sufficient for development of a regional model. Eelgrass cover has been digitized from the Massachusetts DEP aerial images and integrated into the GIS database for all of these estuaries (Figure 8).

Characterization of each estuary and subestuary will require assembly of a GIS database for Cape Cod and the islands. The existing Mass GIS database will provide boundaries, coastlines, streams, place names, land use, and census data. The Cape Cod Commission has delineated ground water watersheds for the Cape. The principal activities here will be digitization of bathymetry from the NOAA charts and characterization of each estuary and subestuary using GIS. Each estuary and subestuary will be characterized as follows:

Biological (from Mass DEP aerial images):

- Eelgrass cover (percent of total area, percent of area < 4m deep)
- Observations of *Ruppia*, *Codium*, and algae in the estuary

Physical (from Mass GIS and NOAA charts bathymetry):

- area
- maximum depth
- mean depth

- inlet width
- inlet length
- inlet maximum depth
- inlet mean depth
- water body type outside of inlet (sound, 1° estuary, 2° estuary)
- Total channel length from estuary or subestuary to sound

Watershed and Land Use:

- Watershed area (ground water). Ground water watersheds have been delineated for Cape Cod estuaries by the Cape Cod Commission.
- Land use (total area in each land use class)
- Population
- Area, land use, and population within 5-year ground water travel time to tidal waters
- Area, land use, and population within 5-to-10 year ground water travel time to tidal waters
- Area, land use, and population greater than 10 year ground water travel time to tidal waters
- Distribution of new construction (< 5 yr old, < 10 yr old) in a watershed

Eelgrass response model for Cape Cod Estuaries. Following characterization of each estuary, data will be plotted to determine whether relationships can be detected from scatterplots. The scatterplots will help determine the most appropriate model: linear, curvilinear, or categorical approaches such as logistic or loglinear models. At least four alternative models will be examined: models using land use directly as a predictive variable, models using estimated nitrogen loading as the predictive variable, and models with and without an estuarine retention time parameter.

Model 1 (simple land use)

$y = a + bx_1 + cx_2 + dx_3 + e$, where
y = eelgrass cover
x_1 = dwellings per unit estuarine surface area in the 0-5 yr travel band
x_2 = dwellings in the 5-10 yr travel band
x_3 = dwellings in the > 10 yr travel band

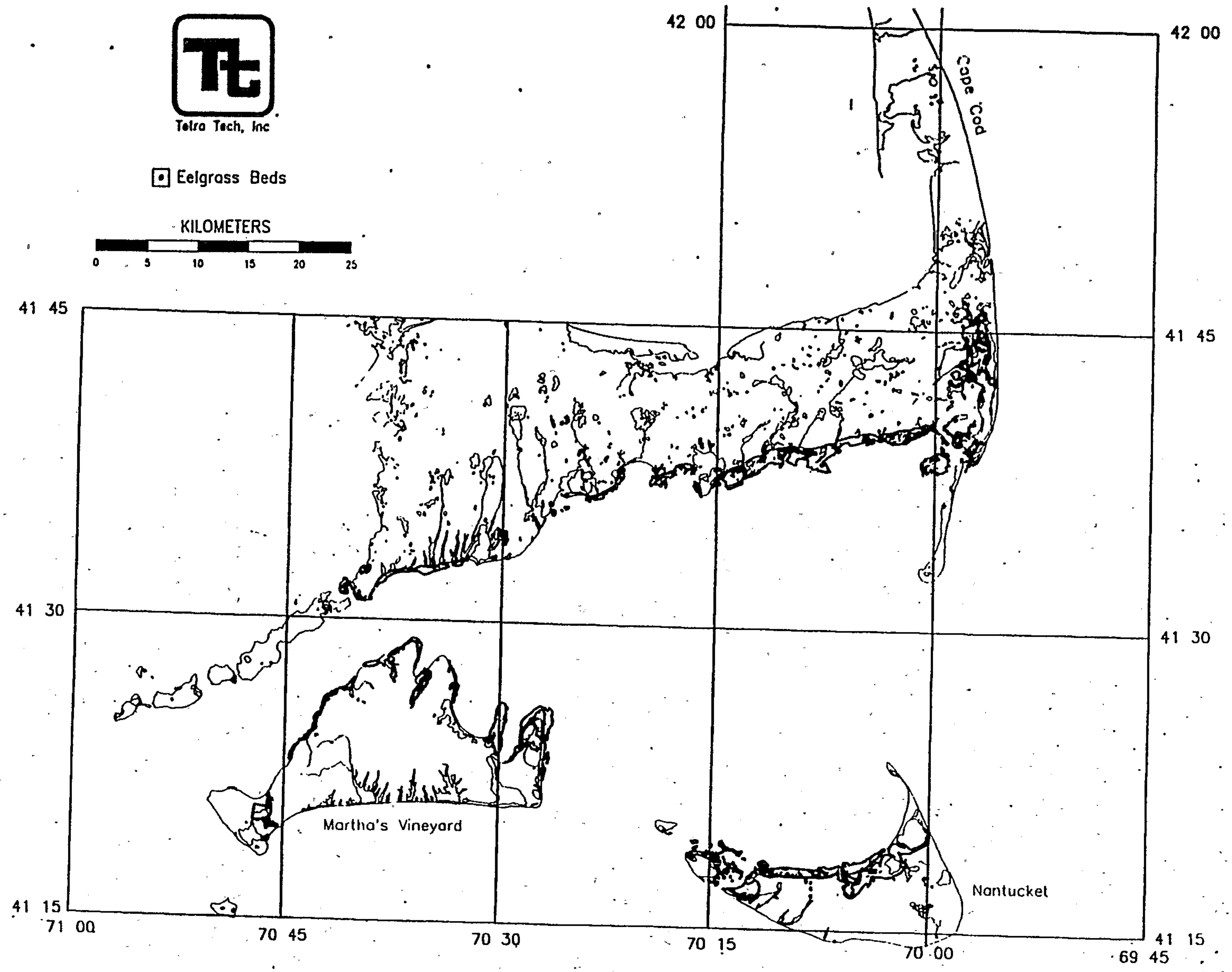

Figure 8. Martha's Vineyard, Nantucket, and south coast of Cape Cod, showing eelgrass beds in 1994 (heavy lines). Eelgrass beds shown only from Woods Hole to Pleasant Bay and on the north coasts of Martha's Vineyard and Nantucket islands (M. Morton, Tetra Tech, Inc.).

Model 2 (estimated N loading)

$y = a + bx + e$, where
x = areal nitrogen loading estimated from one of the N loading models, taking into account the three ground water travel bands and estimated proportion of new construction in each.

Models 3 and 4

Models 1 and 2 might be improved with an estuarine retention time parameter, the Vollenweider parameter (Reynolds, 1984; Costa et al., 1995), but this requires more study:

$V = t_w z^{-1} (1 + \sqrt{t_w})^{-1}$, where
t_w = average hydraulic retention time
z = mean depth
so: $y = V(a + bx + e)$
$y = V(a + bx_1 + Cx_z + dx_3 + e)$

Retention time is difficult to estimate in estuaries because of highly variable wind-induced and tidal mixing during a tidal cycle (Geyer and Signell, 1994). Retention time can be bounded at the upper limit by freshwater inflow assuming no tidal exchange (treating the estuary as a lake), and at the lower limit by freshwater inflow, plus tidal inflow assuming complete mixing every tidal cycle. Actual mean retention time will be somewhere between these two extremes. A first-order approximation for these small estuaries will be to assume 50 percent mixing every tidal cycle, and calculate retention time accordingly. Alternatively, it has been suggested that macroalgae, because they are held fast to one spot, intercept nutrients that are carried past them in water currents and hence are not affected by estuarine retention time. If retention time is unimportant, then the retention time models will perform poorly relative to models 1 and 2.

Uncertainties associated with the eelgrass response model. An objective of risk assessment is to characterize uncertainty and its sources that may play a role in prediction of risk. Sources of uncertainty in the ecological risk assessment include:

- **Alternative hypotheses.** Other explanations or interactions operating that were not addressed or that might impede attainment of management goals might be operating.

- **Model uncertainty.** In the case of the estuarine analysis, there are three competing nitrogen loading models, each of which will be examined for a "best fit" to the eelgrass response data. The resultant "best fit" model is empirical and does not necessarily reflect underlying mechanisms; it seeks only the best fit to the data. However, as long as the predictions of the best fit model hold, it is sufficient for management.

- **Data uncertainty.** Data uncertainty includes data collection methods, adequacy of sample size, random sampling error, and measurement error. Random error (including natural variability) is part of the data distribution and can be analyzed with empirical or Monte Carlo methods.

Uncertainties associated with factors affecting eelgrass. Predictions from the estuarine portion of the risk assessment will include risk of continued eelgrass habitat loss, or, conversely, probability of eelgrass habitat recovery for given nutrient management scenarios. These predictions and probabilities will derive from the empirical models developed in the analysis phase on eelgrass response to predicted nutrient loading. The response model will not cover several alternative and interacting hypotheses that may also contribute to eelgrass loss or may prevent eelgrass habitat recovery. Thus, the models are intended to predict necessary, but not necessarily sufficient, conditions for eelgrass recovery.

Eelgrass requires relatively clear water (Secchi depth = 1-2 m); it will grow in salinities greater than 10-15 ppt, and sediments composed of fine sands or muddy sands (Batiuk et.al. 1992). Necessary and sufficient conditions for eelgrass growth and recovery in Waquoit Bay are:

- Low nitrogen concentrations that are not toxic to eelgrass (<1 μM; Burkholder, 1992) and that permit eelgrass growth while limiting rapid growth of *Cladophora* and *Gracilaria*. *Cladophora* is characteristic of eutrophic habitats. In Sage Lot Pond, a subestuary of Waquoit Bay, *Cladophora* and *Gracilaria* were limited when nitrate concentration was less than 1 μM in the water column and when sediment interstitial ammonia was less than 1.5 μM (Peckol et al., 1994). Similarly, Batiuk et al. (1992) recommended nitrogen concentrations less than 0.15 mg/L DIN (<2.4 μM) to limit phytoplankton growth in eelgrass habitat of the Chesapeake Bay.

  Achieving low nitrogen loading to Waquoit Bay will require some sort of nitrogen source control, as well as a sufficient lag time to allow nitrogen currently in the ground water to be flushed out. Groundwater travel times in the watershed might be several tens of years, depending on distance from a source to a water body (Sham et al., 1995). Management scenarios to be analyzed will include an estimate of the lag time necessary for changes in nutrient supply to take effect in the estuary. A secondary time lag is the pool of nitrogen in the decomposing organic matter, which is thought to be approximately 3 years' supply (Tampa Bay NEP, 1995). The organic nitrogen pool may therefore require 3 to 5 years to equilibrate to a lower level, but this appears to be negligible compared to the time lag in the supply rate.

- Absence of macroalgal and epiphytic growth capable of overgrowing and shading eelgrass. Eutrophication and excess algal production are reversible if nutrient availability is reduced. Achievement of low nitrogen loading and a reduced nitrogen pool in the estuary will result in reduced algal growth.

- Low turbidity and low resuspension of fine organic matter. Because of the sandy soils of Cape Cod, mineral turbidity (silt and clay) is not a problem in Cape Cod waters. In Waquoit Bay, fine organic matter from decomposing algae is resuspended by wind, tide, and boat wakes. This organic matter can settle on eelgrass leaves, enhanced by the surface roughness of epiphytic algae. The epiphytes and the organic sediment shade the leaves and can inhibit eelgrass growth. Although this mechanism of sediment entrapment by epiphytes has been proposed to contribute to SAV loss (e.g., Kemp et al., 1983; Short 1993), it has never been demonstrated to operate in the field or in the laboratory.

Excess organic matter is a consequence of excess production due to nutrient enrichment. If the supply of organic matter is reduced, by reducing nutrient loading and primary production, then the organic matter pool would eventually decline due to decomposition, burial in the sediment, or export from the system. Thus, as long as nutrient loading is reduced, organic matter will decline with it, perhaps delayed by a time lag of 3 to 5 years (Tampa Bay NEP 1995).

- Appropriate sediment for eelgrass growth. Eelgrass can grow in a variety of sediments, including mixtures of sand and mud, fine sands, and other particle sizes (Orth and Montfrans, 1984; Batiuk et al., 1992; Burkholder et al., 1992). The sediment has previously been appropriate for eelgrass growth.

- Appropriate salinity for eelgrass growth (> 10-15 ppt). Available information indicates that Waquoit Bay has not freshened.

- Eelgrass propagules. Existing eelgrass root stocks and seed banks might have been exhausted in the years of decline. Natural recolonization is a random event and depends on nearby seed sources. The remnant eelgrass populations in the subestuaries Hamblin and Jehu Ponds, as well as offshore populations, may provide seeds to Waquoit Bay, but there is no way of knowing when such colonization might occur. Aerial images (1994) show large and extensive eelgrass beds in Vineyard Sound just outside the Waquoit Bay inlet (Figure 8). Alternatively, eelgrass may be planted to restore meadows, if habitat requirements have been met. Restoration (planting) of habitat that meets eelgrass ecological requirements (light, salinity, substrate) has met with mixed success (up to 80 percent survival but variable; Batiuk et al., 1992).

Model uncertainty. The exposure-response models result in an empirical uncertainty, expressed as the confidence intervals of the models. Another type of uncertainty is model uncertainty, or indeterminacy, because it is not known which loading models are correct, or even which one gives the best estimates of nitrogen loading and its sources. In the risk assessment framework, the confidence intervals of the eelgrass response models represent uncertainty of ecological effects, and the indeterminacy of the loadings models represent uncertainty of exposure.

Data Uncertainty. The standard error of predicted values is the uncertainty of the exposure-response model. The exposure model, in turn, has uncertainty due to uncertainty of its input variables. The output uncertainty can be simulated with a Monte Carlo approach and yields a distribution of the output variable, N loading. The N-loading distribution is then combined with distributions of other input variables to the exposure-response model and the uncertainty of the prediction to yield an overall uncertainty of the combined model. The uncertainty can be expressed as a confidence interval or a cumulative distribution.

The final models and their estimated uncertainties can be used to predict the probable consequences of specific management scenarios (e.g., effects of complete planned buildout; effects of sewer installation in selected portions of the watershed, effects of improved septic systems, effects of lawn fertilizer ban). They can also be used to estimate the probability that a management action will fail to achieve its target, and thus, how much effort is necessary to obtain, for example, 90 percent probability of achieving the objective.

2.4.3 Future Nitrogen Loading to Waquoit Bay

The CCC, BBP, and LMR models are steady-state models; however, Sham et al. (1995) demonstrated that nutrient loading to the estuary is not in equilibrium with land use. Nutrient loading and associated ecological effects can lag many years behind changes in land use as a result of the time it takes for ground water to travel from the point of recharge to the estuary; furthermore, the duration of the time lag varies across the watershed. Ground water travel times from some parts of the watershed to the estuary may approach 100 years (Sham et al., 1995). For these reasons, nitrogen loading to the estuary is not a function of land use at any one point in time.

Empirical assessment of the relationship between land use and nutrient loading in Waquoit Bay must take into account the time lag between contamination of ground water at the point of recharge and discharge to the estuary. This can be most effectively accomplished by combining the major elements of the LMER model at the Sham et al. model. A hybrid model should include the variety of sources and loss terms incorporated into the LMER model, as well as the spatio-temporal aspects of the Sham et al. model. Indicators of nitrogen sources will need to be carefully chosen based on availability of historical data. A critical factor to include from the LMER model is attenuation of nitrogen in ground water.

The goal of the hybrid modeling effort will be to produce a time-series of hindcasted and forecasted nitrogen loading rates to Waquoit Bay that incorporates all of the significant sources for which reliable data can be obtained. The form of the model output will be similar to that from Sham et al. (1995). Nitrogen loading rates can then be plotted against measures of ecological effects. These data can be used to aid interpretation of the ongoing, empirical, cross-sectional analysis of current land use and eelgrass extent in Cape Cod estuaries.

The predicted time series of nitrogen loading to Waquoit and observed eelgrass cover can be used to test the regional model developed above. Following testing, the models can be used to predict the effects of different nutrient management scenarios for Waquoit bay.

2.4.4 Potential Future Analysis for Other Stressors

The preliminary comparative risk analysis identified nutrient loading as the dominant stressor in the watershed. This risk assessment will explicitly analyze estuarine nutrient loading, leaving freshwater nutrient loading, habitat alteration, and other stressors for future, more comprehensive analysis. Directions this future analysis could take are discussed below.

Pond Nutrient Loading. Ashumet and Johns Ponds are subject to nutrient enrichment (primarily phosphorus) from ground water and nonpoint runoff.

Objectives

- Characterize expected trophic state of Cape Cod ponds not subject to discharges, residential septic seepage, and suburban lawn and road runoff.
- Characterize current trophic state of Ashumet and Johns ponds from ongoing MMR studies.
- Estimate risk of further eutrophication of the ponds based on projected increases in P loading, using a Vollenweider eutrophication model.

Physical Habitat Alteration. Physical habitat alteration has the greatest potential effects on freshwater stream components and on water dependent wildlife. Effects are well-known: removal of a habitat results in removal of species dependent on that habitat. It is generally not reversible unless the original habitat is restored. Physical habitat alteration in the Waquoit watershed includes beach protection, which changes the dynamics of barrier beaches; road and subdivision construction in nontidal wetlands; and road and development alterations of streams. Except for beach protection, the continuing extent of habitat alteration in the Waquoit watershed is poorly known. Salt marsh is currently protected from further encroachment by development; freshwater wetlands, less so. Habitat of the Quashnet River has been restored, but not in the Childs River. It is not known whether further habitat alteration will take place in these rivers.

A second component is temporary habitat disruption, with no permanent habitat loss. If the disruption is more frequent and more severe than the ability of the system to recover, it can become a permanent loss. Disruption is often a question of overuse, such as by mountain bikes, off-road vehicles, or boats. The principal concern in Waquoit has been boat propellers clipping eelgrass and preventing its recovery.

Objectives

- Measure the present and historical extent of suitable habitat for beach and dune nesting birds.
- Quantify the abundance of plovers and terns in the watershed.
- Correlate habitat and bird abundance data.

Development of habitat loss-response relationship between avian habitat and species abundances. Habitat loss is well known to cause irreversible loss of species dependent on the habitat for a key part of their life cycle. Birds are particularly vulnerable to loss of nesting areas, and fish are vulnerable to loss or degradation of spawning areas. The U.S. Fish and Wildlife Service, the National Biological Service, and the Massachusetts Audubon Society might have information on suitable habitat for beach and dune nesting birds, estimates of past habitat extent, and bird counts or nest counts in the area. If the information is available, it may be possible to determine trends in available habitat and nesting activity over time and in relation to land use and population measurement endpoints.

Eelgrass Disruption. A stress-response relationship between eelgrass and boating activity is more difficult to develop because data are more difficult to obtain and because boating activity and nutrient loading are likely to be collinear in the Cape Cod region. Information from sites with high boating activity but low nutrient loading, and sites with high nutrient loading but low boating activity will be needed. Sargent et al. (1995) documents seagrass scarring from propellers at sites around the coast of Florida.

Alternatively, what information would be required to answer this in the future? A simple experiment would be to cordon off several areas from boat traffic after nitrogen management is implemented. Eelgrass regeneration within the fenced areas but not outside would indicate that boat traffic is significant in inhibiting eelgrass regrowth.

Other Stressors. All other stressors identified in this risk assessment ranked lower in priority in the comparative risk analysis. The MMR toxics assessment will analyze human health risks due to toxic substances in the ponds, and an ecological risk analysis is still needed. For the other stressors, too few data exist for further analysis at this time. Possible hypotheses that would be addressed in later phases of this risk assessment include:

- **Altered riverine flow.** Altered flow in the streams from ground water removal, cranberry cultivation, and storm water runoff decrease stream base flow and increases stormflow, and increase the risk of habitat degradation for anadromous fish and invertebrates in the streams of the watershed.

- **Toxic chemicals.** Toxic chemicals in ground water plumes and from lawn and suburban stormwater runoff increase the risk of loss of freshwater and estuarine fish and invertebrates.

- **Harvest pressure.** Excessive harvest pressure increases the risk of loss of commercial and recreational fish and shellfish in the estuarine and freshwater systems of the Waquoit Bay watershed.

- **Suspended sediments.** Suspended sediments, primarily from resuspension of organic floc by boat wakes in the estuary, increases the risk of loss of eelgrass due to sedimentation of the floc on the eelgrass blades and increased light attenuation, and therefore also increases the risk of loss of estuarine fish and invertebrate habitat.

A future analysis approach would be to assess the extent and magnitude of each of the stressors, to address the question of exposure of the system to the stressors. For example, analysis of altered flow might include determining the stormflow hydrography of the most altered stream (Child's River), and comparing it to less altered streams such as the Quashnet or other rivers. Alteration of base flow could be addressed by analysis of USGS gauge readings. USGS might have determined stormflow hydrographs for streams with a gauging station. If flow alteration is minor, even in the most heavily altered stream, flow alteration is a negligible problem overall.

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APPENDIX A: LIST OF PARTICIPANTS IN THE WAQUOIT BAY WATERSHED CASE STUDY

Waquoit Bay Risk Assessment Team

Suzanne Marcy	Technical Panel Chair, U.S. Environmental Protection Agency, Office of Water
Patti Tyler	U.S. Environmental Protection Agency, Region 1
Maggie Geist	Waquoit Bay National Estuarine Research Reserve
David Dow	National Marine Fisheries Service, Northeast Fisheries Science Center
Jeroen Gerritsen	Tetra Tech, Inc.
Chuck Spooner	U.S. Environmental Protection Agency, Office of Water
Conchi Rodriguez	U.S. Environmental Protection Agency, Office of Prevention, Pesticides and Toxic Substances
Vicki Atwell	U.S. Environmental Protection Agency, Office of Research and Development

Waquoit Bay Risk Assessment Contributors

Edward Eichner	Cape Cod Commission
Joe Costa	Buzzards Bay National Estuary Program
Ivan Valiela	Boston University
Charles Costello	Massachusetts Department of Environmental Protection

Heidi Clarke	Yale University
Tom Cambareri	Cape Cod Commission
Lynn Feldpausch	U.S. Environmental Protection Agency, Region 1
Jack Gentile	U.S. Environmental Protection Agency, Office of Research and Development
Chi-Ho Sham	The Cadmus Group, Inc.

APPENDIX B: NEWSPAPER ADVERTISEMENT AND ARTICLE ON WAQUOIT BAY WATERSHED CASE STUDY

APPENDIX B

NEWSPAPER ADVERTISEMENT AND ARTICLE ON WAQUOIT BAY WATERSHEDCASE STUDY

The US Environmental Protection Agency (EPA), in conjunction with the Waquoit Bay National Estuarine Research Reserve (WBNERR) is proud to announce that the Waquoit Bay Estuary watershed is one of five selected nationwide for participation in an ecological risk assessment case study beginning this fall.

The framework developed for ecological risk assessment is based on the Human Health Risk Assessment format employed successfully by the EPA for the last ten years. This process is designed to identify and evaluate human health "stressors" in a variety of settings and provide this information to those persons effected. A human health stressor is defined as any physical, chemical, or biological entity that can induce an adverse effect on the human organism. Examples of such stressors range from highly toxic substances such as plutonium to less harmful considerations such as ultraviolet solar radiation.

A similar approach is now being applied to whole watersheds. Here, the "ecological health" of the watershed ecosystems is the prime consideration rather than the physical health of human individuals. The Waquoit Bay watershed has been selected as the representative of marine coastal embayments in the case study which begins this fall. Other watersheds which have also been selected include: the Clinch-Powell River in Tennessee, the North Platte River in Nebraska, the Snake River in Idaho and the Big Darby Creek in Ohio.
To initiate resident involvement in this project EPA and WBNERR are holding a:

Public Forum - September 21st - 7 PM
Waquoit Bay Yacht Club.

The purpose of this meeting is to receive input from all on what should be considered as an "ecosystem stressor" in this watershed. An example of one ecological stressor already under scientific investigation at Waquoit Bay is nutrient nitrogen (nitrate). This substance is not a significant *human health* stressor but, because of its effect on the growth and spread of certain marine algae, it has had a major effect on the structure of the Bay's benthic ecosystem.

We invite all persons to attend with their concerns and ideas. This meeting is expressly for the purpose of receiving public input *before* prioritizing and evaluating the ecologic risk factors at Waquoit Bay. Waquoit Bay watershed residents are those with the historical perspective and your input is a highly-valued part of the process. Be assured that all input will be recorded and carefully considered by the project personnel.

The Waquoit Bay Yacht Club is located on Seapit Road just off Rte. 28 near the Childs River crossing. This is just across the river from Edward's Boatyard. If you have any questions about this meeting or, if you have input but are unable to attend, please contact Dr. R. Jude Wilber, Educational Coordinator at WBNERR. 508-457-0495.

The Enterprise
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Tufts Tuesday, September 28, 1993 Page Three

Risk Study Will Be Used To Develop Guidelines To Protect Waquoit Bay

By KATHERINE M. LUSSIER

The EPA has used the process successfully for the past 10 years for the Human Health Risk Assessment, but has not used it to study ecological risks.

The Environmental Protection Agency is performing a risk assessment case study on the Waquoit Bay Estuary that will identify human activities that cause adverse biological, chemical and/or physical effects and will develop guidelines on how to protect the watershed.

About 20 residents met at the Waquoit Bay Yacht Club Tuesday night with officials from the EPA and the Waquoit Bay National Estuarine Research Reserve to offer suggestions on what activities negatively affect the watershed and what resources and values residents want to preserve. The assessment team will also meet with researchers from the research reserve for input.

"We have the experience in doing risk assessments," Patti Tyler, chairman of the Waquoit Bay watershed risk assessment work group said, "but we do not have knowledge of the watershed."

She added that the group was seeking comment from the public because it knows what activities are happening in Waquoit Bay and what resources have been damaged.

Residents identified about 50 stressors — activities that negatively affect an ecosystem — that they wanted the work group to investigate. Some of these stressors included nutrient loading, shellfishing by raking or plunging, building and development, boat speeding, acid rain, and paint and oil on boat bottoms.

In addition, they listed about 25 resources and values they would like to see preserved at Waquoit Bay, including wildlife, habitat, shellfish, finfish, clean water, open space, visual beauty and a recreational atmosphere.

Suzanne Larcey, chairman of the technical committee overseeing the five Ecological Risk Assessment case studies that will be conducted in the nation, said that this study will be the first that examines the combined effects of a chemical, physical and biological stressors on an ecological system.

"A process is needed to assess multiple stressors," Dr. Larcey said.

While many researches have conducted studies on Waquoit Bay, the director, Christine Gault said, they have focused on one issue or one stressor.

"One of the benefits of this project is that it's going to pull together all of the results of these projects," she said.

The study will test a risk assessment process that evaluates and ranks the potential threat of activities on ecological resources and determines how people can protect resources from those threats. The EPA has used the process successfully for the past 10 years for the Human Health Risk Assessment, but has not used it to study ecological risks.

"We need to find a way of pulling all of that information together in a cohesive manner," Dr. Larcey said.

In addition to Waquoit Bay, the River in Tennessee, the Middle Platte Wetlands in Nebraska, the Snake River in Idaho, and the Big Darby Creek in Ohio.

A Unique Watershed

In June, the EPA selected Waquoit Bay as a case study because the estuary is a unique watershed with discrete and identifiable stressors and a large amount local and scientific interest. The work group conducting the study will not gather new data, but will use existing data from former projects.

The work group comprises five officials from the EPA and R. Jude Wilbur, educational coordinator at the reserve.

By November, the group plans to complete the first phase of the process, which is to identify the problems it will examine and what impacts it expects to see.

"This tells us where we need to go," Dr. Larcey said.

The group will then gather and analyze available information on Waquoit Bay. Ms. Tyler said that members have already talked with scientists from the Woods Hole Oceanographic Institution, Boston University and Smith College, who have conducted research on Waquoit Bay.

The last stage of the process is to characterize the risks. Dr. Larcey expects that the group will complete the draft of the risk assessment by next September.

In addition, the group will use the case studies to develop guidelines that will advise residents and researchers on how they can use the study's information effectively and can protect the estuary's resources. Dr. Larcey said that the guidelines will not only be developed for the specific case studies, but can be used for any watershed.

Two offices of the EPA are sponsoring the study. The Risk Assessment Forum wants to test the risk assessment framework for an ecological study and wants to use the information to develop risk assessment guidelines. The Office of Water wants to use the information for watershed planning.

APPENDIX C: RESULTS OF THE WAQUOIT BAY PUBLIC MEETING

A public forum was held September 21, 1993 at the Waquoit Bay Yacht Club. Participants contributed to the identification of what was valuable in the watershed (Table C-1) and to the identification of the principal stressors that might be placing those valuable resources at risk (Tables C-2 and C-3).

Table C-1. Environmental values/concerns that should be protected in the Waquoit Bay watershed.

Environmental Values/Concerns That Should Be Protected	
Open Space Non-Economic Values Historical/Political Perspective Traditional Lifestyles Scenic Views Education Indigenous Wildlife Flyway Integrity (migrating waterfowl) Recreation (swimming) Food Resource Safety Tourists "Historical" Bay Ecosystem Structure "Quality of Life" (pleasant sensual experiences, natural noise, smells, sights, night sky/darkness, freedom to enjoy, visual beauty, access to natural beauty, wildlife, vegetation, pheasants, skunks, clean water, clean air) Shellfishery Shellfishing "Clean" Water Shoreline Human Serenity	Marshland Upland-Marsh Ecotone "Habitat" Recreational "Atmosphere" Water Quality Flushing Rates Air Quality Questions on General "Health" of Existing Ecosystem(s)-Health As Measured, (re: only identified "active" stressor) Washburn Island Human Health and Domestic Animals Health (re: lyme disease) Habitat Striped Bass Navigation Ground Water Quality Eel Grass Wildlife Marine Organisms Finfishery Finfishing Herring Aquifer Integrity (flow rates)

Table C-2. Types of stressors affecting the Waquoit Bay watershed.

Stressor	Chemical	Physical	Biological
Dredging	X	X	
Commercial Overfishing Outside of the Bay			X
Commercial Trawling		X	
Water Withdrawal & Effect of Groundwater/Surface Water Relationship	X	X	
Non-Native Species			X
Bacterial Population			X
Acid Rain	X		
Ignorance, Lack of Education			
Nutrient Loading —Fertilizers for Lawn, Golf Courses and Agriculture; Sewage Treatment Plants; Acid Rain; Road Runoff; Boats; Livestock & Pets; Wildlife (Waterfowl)	X	X	X
Boat Prop Disturbance		X	
Shellfishing —Raking; Plunging		X	
Waterfowl			X
Boat Wake Disturbance		X	
Overpopluation —Uncontrolled Growth, Uncontrolled Access		X	X
Habitat Loss —Loss of Ecotone Between Marsh and Upland; Trampling of Marsh by Boats and People; Unmonitored Campling; Upland Development Resulting in Sedimentation and Hydrologic Changes		X	X
Lack of Values			
Non-Nutrient Runoff	X		X
Man-Made Noise		X	
Historic Fuel Dumping —Residual Contamination within the Atmosphere	X		
Wet Deposition	X	X	X
Dry Deposition	X	X	X
Regional Air Transport and Patterns	X		
Ignorant Tourists			
Apathy			
Fertilizers —Insecticides, Pesticides	X		X
Global Warming		X	X

Table C-2. Types of stressors affecting the Waquoit Bay watershed (continued).

Stressor	Chemical	Physical	Biological
Sea Level Rise		X	X
Catastrophic Storms —Nor'Easter, Hurricanes		X	
Boating Impacts from Shade and Anchorage		X	X
Docks and Piers		X	
Boat Bottom Paint, Oil and Fuel	X		
Boat Speeding		X	
Shoaling > Loss of Flushing within Bay		X	X
Building/Development		X	X
Careless Disposal of Chemicals	X		
Uncontrolled Drainage —Road Runoff, Agricultural	X		
Lead Shot	X		
Cresote on Pilings	X		
Copper Arsemate on Pilings	X		
Underground Storage Tanks	X		
Lyme Disease —Ticks, Deer, White-Footed Mouse (Vectors)			X
Lack of Management	X	X	X
Short-Term Economic Values	X	X	X
Otis Air Force Base	X	X	
Willful Destruction of Natural Resources		X	
Lack of Enforcement	X	X	X

Table C-3. Waquoit Bay watershed stressors and ecological effects.

Source	Stressor	Type	Ecological Effects
Septic systems, fertilizers, atmospheric deposition	Nitrogen	Chemical	Increase in macroalgae and phytoplankton growth
Septic systems	Pathogens	Biological	Introduction of pathogens and fecal coliforms to surface water
Septic systems	Fecal coliforms	Biological	Shellfish bed closures
Nutrient input	Shading by macroalgae	Physical	Alteration of substrate and decrease in light attenuation
Nutrient input	Shading by macroalgae	Biological	Major faunal alterations in benthic and fish communities
Nutrient input	Increase in macroalgal growth	Biological	Alteration of macroalgal species composition Loss of habitat for submerged aquatic vegetation Loss of spawning sites for fish Loss of hiding places and protection of fish Loss of scallop larvae settling habitat
Nutrient input	Increase in macroalgal growth	Physical	Change in water coloration
Macroalgal growth	Increased respiration of macroalgae	Chemical	Decrease of dissolved oxygen within the water column. An increase in respiration rates in combination with a temperature and cloud cover increase=anoxic events
Macroalgal growth	Increased respiration of macroalgae	Biological	Mortality within benthic invertebrate and fish populations
Macroalgal growth	Competition by macroalgae	Biological	Loss of eelgrass habitat
Unleashed dogs, gulls, crows, red fox, and eastern coyote	Wild predators	Physical and biological	Disturbing nesting areas for two endangered species—piping plover and least tern and the threatened roseate tern
Mute swan	Introduction of exotic species	Biological	Displacing native waterfowl species
Fertilizers and septic systems	Phosphorus	Chemical	

Table C-3. Waquoit Bay watershed stressors and ecological effects (continued).

Source	Stressor	Type	Ecological Effects
Marinas and piers	Antifouling chemical leachate	Chemical	Negative biological effects on organisms in contact with it
Gasoline, motor oil, Automobile and boat engines	Organic compounds acetone, benzene, naphthalene, petroleum hydrocarbons, polychlorinated biphenyls and creosote	Chemical	?
Massachusetts Military Reservation (Otis Air Force Base)	*Methylene chloride, *cis* 1,2 dichloroethy-lene, 1,1,1-trichloroethane, trichloroethy-lene, perchloro-ethane, 1,2-DBA, toluene, ethylbenzene, xylene in Sergou Phase I Field GC Screening Data	Chemical	?
Massachusetts Military Reservation (Otis Air Force Base)	DCE, TCE, PCE, in Ashumet Valley Groundwater Plume	Chemical	?
Lawns, golf courses, cranberry bogs	Need information	Chemical	?
Road deicing salt	Need information	Chemical	Phytotoxicity, leaf fall
Landfill leachates	Unrecorded dump sites (need more information)	Chemical	?
?	Metals— arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, silver, zinc	Chemical	Looking into obtaining information from the EMAP program
	Hurricanes or severe storms	Physical	Flooding of upper estuary Shoreline erosion Altered tidal regime Increase volume of water input Sediment resuspension

Table C-3. Waquoit Bay watershed stressors and ecological effects (continued).

Source	Stressor	Type	Ecological Effects
	Seawalls and jetties	Physical	Major alteration of shoreline dynamics Sediment resuspension Coastal erosion Sediment buildup Change in flushing rates
	Boat propellers	Physical	Rip-up vegetation Sediment resuspension Increased turbulence and mixing in water column
	Polar outbreaks	Physical	Freezing of bay
Commercial shellfishing	Raking and plunging for scallops	Physical	Disturbing sediment Resuspending nutrients Increasing turbidity
Construction development	Filling wetlands	Physical	Loss of marsh-uplands ecotone Increase surface water runoff (activities such as paving to lead to an increase in surface water runoff temperature) Increase sediment loading Alter groundwater flow
Otis Air Force Base	Thermonuclear explosion	Physical	Intense heat and the end of life as we know it
Global climate change	Sea level rise and increase in turbidity and sediment loading	Physical	Flooding Alteration on coastline Increase in turbidity and sediment loading
	Dredging channels	Physical	Sediment disturbance and increase in turbidity

APPENDIX D: WAQUOIT BAY MANAGEMENT GOALS MEETING

Attendees

Tom Cambareri	Cape Cod Commission
Bruce Carlisle	Massachusetts Coastal Zone Management
Joe Costa	Buzzards Bay National Estuary Program
David Dow	National Marine Fisheries Service, Northeast Fisheries Science Center
Perry Ellis	Mashpee Harbor Master
Tom Fudala	Mashpee Planning Department
Jeroen Gerritsen	Tetra Tech, Inc.
Steve Hurley	Massachusetts Division of Fisheries and Wildlife
Chuck Lawrence	Cape Cod Commission
Sandy McLean	Citizens for the Protection of Waquoit Bay
Carl Melberg	U.S. Fish and Wildlife Service
JoAnn Muramoto	Falmouth Conservation Commission
Mark Patton	Otis Installation Restoration Program
Pam Polloni	League of Women Voters, Falmouth
Bob Sherman	Mashpee Conservation Commission
Jan Smith	Massachusetts Coastal Zone Management
Patti Tyler	U.S. Environmental Protection Agency, Region 1
Mary Varteresian	U.S. Fish and Wildlife Service
Brooks Wood	Monomoscoy Improvement Trust
Rick York	Mashpee Shellfish Department

Waquoit Bay Concerned Organizations

Ashumet - John's Pond Association

Ashumet Valley Property Owner's Association, Inc.

Association for the Preservation of Cape Cod

Atlantic States Marine Fisheries Commission

Barnstable County Department of Health and Environment

Cape and Islands Coastal Waters Steering Committee

Cape and Islands Self Reliance Corporation

Cape Cod Beagle Club

Cape Cod Commission (CCC)

Cape Cod Cooperative Extension Service

Citizens for the Protection of Waquoit Bay

Davisville Association

F. A. C. E. S.

Falmouth Rod and Gun Club

Falmouth Condo Trust

Green Briar Nature Center

Mashpee Briarwood Association, Inc.

Massachusetts Audubon Society

Massachusetts Coastal Zone Management (CZM)

Massachusetts Department of Environmental Management (MADEM)

Massachusetts Department of Environmental Protection (MADEP)

Massachusetts Department of Fisheries, Wildlife, and Environmental Law Enforcement

Massachusetts Heritage Society

Massachusetts Military Reservation (MMR)
Menauhant Harbor Association

National Oceanographic and Atmospheric Administration (NOAA) National Estuarine Research

Reserve System (NERRS)

NOAA National Marine Fisheries Service (NMFS)

National Science Foundation (NSF) Land Margin Ecosystems Research (LMER)

The Nature Conservancy

Seacoast Shores Owners Association

Shorewood Beach Owners

Sierra Club - Cape Code Group

South Cape Beach Advocates

The 300 Committee, Inc.

Town of Falmouth

Town of Mashpee

Town of Sandwich

Trout Unlimited

U.S. Army Corps of Engineers (COE)

U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS)

U.S. Fish and Wildlife Service (USFWS)

U.S. Geological Survey

Wampanoag Tribal Council

Waquoit Bay National Estuarine Research Reserve (WBNERR)

Waquoit Bay Watershed Citizens Action Committee (formed of representatives of other groups)

Waquoit Bay Watershed Intermunicipal Committee

Waquoit Bay Yacht Club

APPENDIX E: ASSESSMENT OF AVAILABLE INFORMATION

A summary of the assessment of available information was provided in Section 2.1 of the Waquoit Bay Problem Formulation. The following material describes in more detail the ecosystems at risk, reviews ecological effects that have been observed in the watershed, and provides a preliminary characterization of stressors in the Waquoit Bay watershed based on studies conducted in the watershed and elsewhere.

E.1 Characterization of the Ecosystems at Risk

The Waquoit Bay watershed covers approximately 53 square kilometers (21 square miles) and spans parts of the towns of Falmouth, Mashpee, and Sandwich on the south coast of Cape Cod, Massachusetts. The watershed was first delineated by Babione (1990) and further refined by Cambareri et al. (1992). Recent work by Brawley and Sham (in prep.) reinterpreted the watershed delineation of Cambareri et al. (1992) to develop a three-dimensional model of the drainage basin. The watershed covers 8 km (5 mi) from the head of the Bay to the regional ground water divide in the vicinity of Snake Pond (Figure E-1). The Bay and its tributaries encompass a total surface water area of 3.9 km^2/389 ha (1.5 mi^2). The major surface water components of the watershed include the Waquoit estuary, two major rivers and several smaller streams, freshwater ponds, and freshwater wetlands. Within the Waquoit Bay watershed are seven subwatersheds (Childs River, Sage Lot Pond, Quashnet River, Eel Pond, Head of the Bay, Hamblin Pond, and Jehu Pond) and four ponds (Ashumet, Johns, Snake, and Flat). These subwatersheds provide diverse habitats that support a variety of ecological communities, including barrier beaches along the Atlantic Ocean, eelgrass beds, saltwater and freshwater marshes, erosion and accretion areas, coastal sand dunes, brackish water ponds, fish spawning and nursery areas, and wildlife habitat.

E.1.1 Watershed-wide Characteristics

The Waquoit Bay watershed lies entirely within the Mashpee pitted outwash plain (LeBlanc et al., 1986), a geologically young landform composed of glacial materials deposited on top of bedrock toward the end of the Wisconsinian Glacial Stage, about 12,000 years before present (Oldale, 1992). Outwash plains were created by broad meltwater streams which size-sorted the drift materials depositing the heavier boulders and pebbles near the glacial margin and gravel and sands further away. Because Cape Cod is so young geologically, the glacial materials have not been significantly altered, resulting in a generally sandy, porous soil throughout the area. In addition to gravel and sand, there are clay and silt lenses; this finer grained material generally is found in deeper sediments to the south.

The term "pitted "refers to the numerous kettle ponds dotting the landscape. Kettle ponds mark the sites where blocks of ice were buried by sediment-laden meltwater streams beyond the glacial margin. Johns Pond and Ashumet Pond are two examples of kettle ponds in the watershed (HAZWRAP, 1995). Waquoit Bay, itself, may have originated as a kettle pond. The southern margin of the bay was flooded by sea-level rise at the close of the Wisconsinan Glacial Stage, when the ice sheet retreated, inundating low lying coastal areas and raising the water table inland due to hydrostatic pressure at the saltwater-freshwater interface. The action of winds, waves and currents continually eroded and displaced the loose glacial sand and gravel contributing to the formation of coastal sand dunes, sea cliffs, barrier beaches and salt marshes. These processes continue to alter the dynamic shore (Oldale, 1992).

Waquoit Bay's geology controls the region's hydrology, which is typical of a glacial outwash plain. The Bay, 1.2 km (4,000 ft) wide and 3.4 km (11,000 ft) long, is a shallow estuary, average depth of 0.9 m (3 ft), fed by freshwater streams and ground water with tidal exchange to Vineyard Sound through two dredged and maintained channels, and a recent breach caused by overwash during Hurricane Bob in August 1991 (Valiela et al., 1996). Fifty percent of the water entering Waquoit Bay comes from the Quashnet and Childs Rivers, 23 percent from direct precipitation, and 27 percent from ground water recharge in the watershed. Ground water in the Cape Cod region is generally formed by precipitation. Ground water recharges the area upgrade from the ponds and discharges from the downgradient portions of the ponds (Cambareri et al., 1992). The rivers derive most of their water from ground water discharge, draining the shallow surface aquifer. Ground water is forced to the surface as the permeable aquifer thins from north to south in the watershed.

The unconsolidated sediments of Cape Cod make ideal aquifers–underground areas that contain enough water to supply significant amounts of water for community use. The permeable aquifer ranges from about 46 m (150 feet) thick near Snake Pond, thinning to 9 m (30 feet) near Waquoit Bay (Garabedian et al., 1991; Cambareri et al., 1992). The porous soils support rapid percolation of rain, nutrients, and contaminants into the subsoil and eventually to the ground water. In recognition of the unique ground water characteristics of Cape Cod, the U.S. Environmental Protection Agency declared this region a Sole-Source Aquifer in 1982, a designation designed to facilitate protection of the water supply. In actuality, the Cape Cod aquifer can be subdivided into six ground water "lenses" or areas of elevated ground water; surface features, such as rivers, separate the lenses and generally ground water does not flow between lenses. The Waquoit Bay watershed lies within the Sagamore or western Cape lens of the Cape Cod Aquifer (Guswa and LeBlanc, 1981).

The watershed's hydrology and habitats are influenced by its climate, which is similar to that of other areas in the northeastern United States but typically has milder winters and cooler summers due to surrounding ocean waters. January and February are the coldest months and July and August are the warmest months. Fog may be common in the spring and summer and humidity is typically high in the summer. Annual precipitation is between 107 and 112 cm (42 and 44 inches), ground water recharge is approximately 45 percent of the total precipitation. Snowfall is variable from one year to the next but is close to 76 cm (30 inches) per year. Between October and April the prevailing winds are northwest whereas from May to September winds come from the southwest. Hurricanes are most common in the late summer and early fall and "northeasters" may occur in winter and early spring.

The surface water ecosystems in the lowlands and uplands of the Waquoit Bay watershed contain several critical habitats identified by the Association for the Preservation of Cape Cod (VanLuven, 1991), including coastal plain pond shores, anadromous fish runs, salt marshes, eelgrass, barrier beaches, and woodlands. Habitats in the watershed are also affected by the southward-flowing cold Gulf of Maine waters and the northward-flowing warm Gulf Stream, which mix off the coast of Cape Cod to form a biological transition zone between the Virginian (temperate) and Acadian (boreal) biogeographic provinces (Ayvazian et al., 1992). This overlap produces more diverse communities than occur in either province. The Waquoit Bay watershed also lies near the Atlantic coast flyway, an important migratory corridor for many coastal and arctic-nesting birds, particularly shorebirds, as well as state and federally protected species. The flora of the watershed include scrub oak and pitch pine forests (Bailey, 1995); forests covered 2650 ha (6548 acres) of the watershed in 1990 (Appendix F). Among the state protected plant species found in the watershed are the sandplain gerardia, *Agalinis acuta* (endangered); the bushy rockrose, *Helianthuemum dumosum* (threatened); the knotroot foxtail, *Setaria geniculata* (of special concern); and the butterfly-weed, *Asclepias tuberosa*, little ladies' tresses, *Spiranthes tuberosa*, eastern lilaeopsis, *Lilaeopsis chinensis*, New England blazing star, *Liatris borealis*, thread-leaved sundew, *Drosera filiformis*, vetchling, *Lathyrus palustris*, and wild rice, *Zizania aquatica*, (on the watch list) (WBNERR, 1993). The following subsections describe in more detail the physical characteristics and biota of each of the four major surface water components of the watershed.

E.1.2 Waquoit Estuary

Waquoit Bay is located at the southern margin of the watershed, protected from Vineyard Sound by a barrier beach east of the main inlet to the Bay, South Cape Beach, and Washburn Island, a barrier island to the west of the inlet (WBNERR, 1989). Water from the Sound enters the Bay through two channels and the overwash breach mentioned above. Several brackish water ponds (Sage Lot, Jehu, Hamblin, and Eel) connect to the Bay. Waquoit Bay is relatively shallow and salt marshes occur in some areas along the margins of the coastal ponds and tributaries (according to aerial interpretations of land use); saltwater wetlands covered 129 ha (319 acres) in 1990 (Cape Cod Commission, unpublished; Appendix F). Bottom habitats include areas of open sand and mud, as well as patches of eelgrass.

Eelgrass (*Zostera marina*) is a rooted vascular plant that grows subtidally on mud to gravel bottoms in zones of fast moving or quiet waters where salinity ranges between 20 and 32 parts per thousand. Eelgrass roots and rhizomes are believed to decrease erosion and increase sedimentation, and eelgrass blades may act to promote deposition by interrupting water flow and trapping suspended sediments, thus, adding to the available food within the meadow (Short, 1984; 1989). Eelgrass is highly susceptible to adverse changes in water quality conditions and requires clear waters with ample light penetration for photosynthesis and suitable levels of nitrogen and phosphorus nutrients (reviewed in Dennison, 1987; Zimmerman et al., 1991; Murray et al., 1992; Dennison et al., 1993; Submerged Aquatic Vegetation Work Group, 1995). Eelgrass provides optimum physical and chemical environmental conditions in a protective habitat for many fishes and invertebrates (Valiela et al., 1992; Heck et al., 1989; Thayer et al., 1989). A variety of bryozoans, sponges, and hydroids attach to eelgrass blades; numerous juvenile finfish, crustaceans, and shellfish inhabit eelgrass meadows. Decaying eelgrass leaves provide food for the detritivores in the benthic community as well. Greater species richness and abundance has been found in eelgrass beds than in adjacent unvegetated areas in Waquoit Bay and Nauset Marsh on Cape Cod (Valiela et al., 1992; Heck et al., 1989).

The overlapping biogeographic ranges are evident in the waters of the estuary, with both year-round residents and seasonal migrants in the finfish communities of Waquoit Bay. A 1968 survey reported that Waquoit Bay had the greatest diversity of finfish species in comparison to nine other Massachusetts estuaries (Curley et al., 1971). The resident species include such species as mummichug (*Fundulus heteroclitus*), striped killifish (*Fundulus majalis*), tidewater silverside (*Menidia beryllina*), fourspine stickleback (*Apeltes quadracus*), and rainwater killifish (*Lucania parva*), Of the 52 species collected in Waquoit Bay, these resident species comprise 35 percent of the total, with these species dominating the abundance (46 percent) and biomass (41 percent) of the overall finfish community (Ayvazian et al., 1992). Table E-1 contains a list of fishes found in the Waquoit Bay watershed.

The part-time residents represent a composite of estuarine spawners such as winter flounder (*Pleuronectes americanus*), longhorn sculpin (*Myoxocephalus octodecemspinosus*), scup (*Stenotomus chrysops*), and tautog (*Tautoga onitis*); marine species which are estuarine visitors, such as the sand lance (*Amodytes americanus*), summer flounder (*Paralichthys dentatus*), and American pollack (*Pollachius virens*); nursery species or young-of-the-year, such as winter flounder juveniles, mullets (*Mugil cephalus*), juvenile tautogs, menhaden (*Brevoortia tyrannys*), Atlantic silversides (*Menidia menidia*), bluefish (*Pomatomus saltatrix*), and bay anchovy (*Anchoa mitchilli*); and adventitious species which have a more southern distributions but which lack an apparent estuarine dependence, such as ladyfish (*Elops saurus*), halfbeak (*Hemiramphus brasiliensis*), and crevalle jack (*Caranx hippos*). Alewives (*Alosa pseudoharengus*) and blueback herring (*Alosa aesivalis*) cross Waquoit Bay on their annual spawning migrations to fresh water, and larger fish such as bluefish and striped bass (*Morone saxitalis*) enter in pursuit of smaller prey fish. Many primarily marine fishes use the estuary in the winter as a spawning and nursery ground. Bluefish, tomcod (*Microgadus tomcod*), white hake (*Urophycis tenuis*), and pollock inhabit the bay as juveniles but are rarely present as adults (Boesch and Turner, 1984).

Shellfish species harvested in the estuary include bay scallops (*Argopecten irradians irradians*), found in the eelgrass habitat, and hardshell (*Mercenaria mercenaria*) and softshell (*Mya arenaria*) clams, generally found in the sand and mud habitats, respectively. The biota of the estuary also includes a variety of temperate and boreal species of planktonic and benthic algae and invertebrates, providing food resources for the finfish and shellfish, as well as terrestrial and avian wildlife in the watershed.

Numerous shorebirds use the barrier beach and coastal saltmarsh as an important stopover on their spring journeys north to breeding grounds in Canada and on their fall journeys south to the southern United States, Central and South America. Shorebirds appearing in abundance in the spring and fall on Waquoit Bay's barrier beaches include black-bellied (*Squatarola squatarola*) and semipalmated (*Charadrius semipalmatus*) plovers; sanderlings (*Crocethia alba*); dunlin (*Calidris alpina*); semipalmated (*Ereunetes pusillus*), least (*Pisobia fusicollis*), and western sandpipers (*Pisobia minutilla*); ruddy turnstones (*Arenaria interpres*); willets (*Catoptrophorus semipalmatus*); lesser (*Totanus flavipes*) and greater (*Totanus melanoleucus*) yellowlegs; and short-billed dowitchers (*Limnodromus griseus*). Sharp-tailed sparrows (*Ammodramus cudacutus*), black-crowned night-herons (*Nycticorax nycticorax*), snowy egrets (*Leucophoyx thula*), and mute swans (*Cygnus olor*) are found in the saltmarshes. Several species of birds that use the waters as nesting or feeding grounds are state and federally protected species.

The piping plover (*Charadrius melodus*), listed as threatened, and the least tern (*Sterna antillarum*), listed as being of special concern, nest on South Cape Beach and Washburn Island. The roseate tern (*Sterna dougalli*), a species listed as endangered, forages in the water and rests on the beach proper (WBNERR, 1993; 1995).

Table E-1. Fishes of the Waquoit Bay Watershed.
Sources: A = Ayvazian et al. (1992); C = Curley et al. (1971); H = Hurley (1990, 1992).

Genus/ Species	Common Name	Reference	Genus/Species	Common Name	Reference
Estuarine Residents					
Opsanus tau	oyster toadfish	A,C	*Gasterosteus aculeatus*	threespine stickleback	A,C
Fundulus heteroclitus	mummichog	A,C,H	*Gasterosteus wheatlandi*	blackspotted stickleback	A,C
Fundulus majalis	striped killifish	A,C	*Syngnathus fuscus*	northern pipefish (in eelgrass)	A,C
Cyprinodon variegatus	sheepshead minnow	A,C	*Menticirrhus saxatilis*	northern kingfish	A,C
Lucania parva	rainwater killifish	A,C	*Gobiosoma bosci*	naked goby	A
Menidia beryllina	inland silverside	A	*Pholis gunnellus*	rock gunnel	A,C
Menidia peninsulae	tidewater silverside	C	*Myoxocephalus aenaeus*	gruby	A,C
Pungitius pungitius	ninespine stickleback	A,C	*Trinectes masculatus*	hogchoker	A,C
Apeltes quadracus	fourspine tickleback	A,C,H	*Sphoeroides maculatus*	northern puffer	A,C
Estuarine Nursery					
Clupea harengus	Atlantic herring	A	*Pomatomus saltatrix*	bluefish	A,C
Brevoortia tyrannus	Atlantic menhaden	A,C	*Tautoga onitis*	tautog	A,C
Anchoa mitchelli	bay anchovy	A	*Tautogolabrus adspersus*	cunner	A,C
Microgadus tomcod	Atlantic tomcod	A,C	*Mugil cephalus*	striped mullet	A,C
Strongylura marina	Atlantic needlefish	A,C	*Pleuronectes americanus*	winter flounder	A,C
Menidia menidia	Atlantic silverside	A,C	*Urophycis tenuis*	white hake	C
Diadromous (anadromous and catadromus)					
Anguilla rostrata	American eel	A,C,H	*Alosa sapidissima*	American shad	A
Alosa aestivalis	blueback herring	A,C	*Asmerus mordax*	rainbow smelt	C
Alosa pseudoharengus	alewife	A,C			

Table E-1. Fishes of the Waquoit Bay Watershed (continued).
Sources: A = Ayvazian et al. (1992); C = Curley et al. (1971); H = Hurley (1990, 1992).

Genus/ Species	Common Name	Reference	Genus/Species	Common Name	Reference
Marine, Seasonal Visitors as Adults					
Anchoa hepsetus	striped anchovy	A	*Prionotus carolinus*	northern searobin	A, C
Pollachius virens	pollock	A, C	*Prionotus evolans*	striped searobin	A,C
Morone saxatilis	striped bass	A, C	*Myoxocephalus octodecemspinosus*	longhorn sculpin	C
Centropristis striata	black sea bass	A, C	*Paralichthys dentatus*	summer flounder	A,C
Stenotomus chrysops	scup	A, C	*Scophthalmus aquosus*	windowpane	A
Mugil curema	white mullet	A	*Limanda ferruginea*	yellowtail flounder	A
Ammodytes americanus	American sandlance	A, C			
Freshwater, Sometimes in Brackish Water					
Fundulus diaphanus	banded killifish	A, C	*Etheostoma olmstedi*	tesselated darter	H
Fundulus confluentus	marsh killifish	A	*Salvelinus fontinalis*	"sea run" eastern brook trout	C,H
Morone americana	white perch	A, C	*Salmo trutta*	brown trout	H
Notemigonus crysoleucas	golden shiner	C, H	*S. fontinalis x S. trurra*	tiger trout (hybrid)	H
Notropis bifrenatus	bridle shiner	A	*Ameiurus nebulosus*	brown bullhead	H
Notropis heterolepis	blacknose shiner	A	*Lepomis gibbosus*	pumpkinseed	H
Catostomus commersoni	white sucker	C, H	*Micropterus salmoides*	largemouth bass	H
Adventitious Visitors					
Elops saurus	lady fish	A	*Hyperoglyphe perciformis*	barrelfish	A
Caranx hippos	crevalle jack	A	*Gadus morhua*	Atlantic cod	C
Hemiramphus brasiliensis	ballyhoo	A	*Cyclopterus lumpus*	lumpfish	C

E.1.3 Coastal Plain Rivers

Coastal plain rivers also provide an important source of water for upland species and are prime habitat for fishes, turtles, ducks, and geese. Forests of scrub oak and pitch pine are frequently encountered in the surrounding soils, which are mostly consolidated sand dunes. The largest and cleanest contributor of fresh water to Waquoit Bay is the Quashnet River (also called the Moonakis River in Falmouth), which had an average streamflow of 391 L/sec (13.8 cubic ft/sec) or 8.9 million gallons per day from 1988 to 1991 (Barlow and Hess, 1993). The Quashnet originates in a spring-fed cedar swamp at the top of John's Pond. Outflow from Johns Pond to the Quashnet can be regulated by a gate-controlled spillway. From the pond, the river enters cranberry bogs, flows east for 0.6 km (0.4 mi) then flows south for 5.6 km (3.5 miles) (Baevsky, 1991), finally emptying into Waquoit Bay.

Besides providing a source of fresh water to Waquoit Bay, the Childs and Quashnet Rivers provide a relatively rare and shrinking habitat for several anadromous and catadromous finfish species (Baevsky, 1991). Brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), alewife (*Alosa aestivalis*), white perch (*Morone americana*) use these rivers as a conduit for spawning grounds either within the rivers themselves or within John's Pond (McLarney, 1988; S.T. Hurley, 1994, Massachusetts Divsion of Fisheries and Wildlife, pers. comm.). American eels (*Anguilla rostrata*) use these rivers as a conduit for spawning grounds in the open sea. These species require very specific ranges of certain water quality parameters (temperature, pH, dissolved oxygen, salinity) which may vary over the stages of egg, larval and juvenile development (Hunter, 1991). Under the care of the Northeast Chapter of Trout Unlimited, ecological integrity and stability in the Quashnet have recently improved significantly. The river now hosts a 1.6 km- (1 mi-) long trout spawning reach 3.5 to 5.3 km (2.2 to 3.3 mi) downstream from the spillway. The upper Quashnet River receives constant temperature groundwater discharge through the sand and gravel bottom (USGS, 1991), which keeps river temperatures moderate, from 10 °C to 17.9 °C (50 °F to 64 °F) in the spawning reach (Baevsky, 1991). Blueback herring, striped bass, and white sucker (*Catastomus commersoni*) are also commonly found in this stream.

The characteristics of the high volume of ground water inputs into the Quashnet River significantly influence the water quality parameters of the river. At present, the waters seeping into the Quashnet are fairly pristine, with a dissolved oxygen content of 9.3 to 12.6 mg/L, (well above the minimum requirements for the most sensitive brook trout), pH between 6.0 and 6.4 (too low for the Class B requirements), and a nearly constant temperature of 14 °C (57 °F) resulting from groundwater seepage (Baevsky, 1991). For example, the temperature remained between 10 °C and 17.9 °C (50 °F and 64 °F) in the spawning reach during 1988 (Baevsky, 1991). In that same year, the temperature entering the river from John's Pond was 26.3 °C (79 °F). The inputs from ground water are also crucial to maintaining sufficient volume in the river for fish to move upstream.

The good water quality of the Quashnet River also provides habitat for a variety of macroinvertebrates which serve as a food source for the finfish communities (Pennak, 1989). As part of Trout Unlimited's restoration project, macroinvertebrate species were reintroduced to the Quashnet from other freshwater streams. A survey done in 1982-1983 found species representing the Trichoptera (caddisfly), Diptera (true flies), Lepidoptera (butterflies and moths), Ephemeroptera (mayflies), and Plecoptera (stoneflies) orders (Wright, 1987). Stoneflies, and to some extent mayflies and caddisflies, are good indicators of healthy water quality as they require fairly high levels of dissolved oxygen.

E.1.4 Freshwater Ponds

Ashumet Pond and Johns Pond are coastal plain kettle hole ponds located within the Waquoit Bay watershed, north of the bay itself. There are no surface outlets discharging from Ashumet Pond. Ground water recharge occurs in the upgradient area and the pond recharges the ground water on the downgradient side of the aquifer. Johns Pond connects to the Quashnet River by a surface outlet at a gate-controlled spillway. This spillway can draw down the level of Johns Pond to 1.2 m (4 ft) below it average elevation. Ashumet Pond covers 82 ha (203 acres), with an average depth of 7 m (23 ft) and maximum of depth of 20 m (66 ft); Johns Pond covers 131 ha (324 acres), with an average depth of 5.9 m (19 ft) and maximum depth of 19 m (62 ft) (Duerring and Rojko, 1984a; 1984b).

Fish populations including largemouth (*Micropterus salmoides*) and smallmouth (*Micropterus dolomeiui*) bass, trout , and brown bullhead catfish (*Ameiurus nebulosus*) reside within Ashumet Pond and similar fishes have been recorded in Johns Pond. Freshwater mussels are also abundant in the ponds. A high diversity of phytoplankton is present in the photic zone, but limited vegetative growth on the shorelines has been documented (HAZWRAP, 1994, 1995). Within the vicinity of the ponds, several species have been designated as having special concern or threatened status, including the sandplain flax, the marsh hawk, and the grasshopper sparrow . The upland sandpiper is listed as a state endangered species.

E.1.5 Freshwater Wetlands

The freshwater wetlands of the Waquoit Bay watershed covered approximately 83 hectares in 1990 (Appendix F) and support many wetland plant and animal species. Important freshwater wetlands include the Ashumet and Johns Ponds shorelines. Waterfowl are dependent upon these wetlands for breeding, foraging and migratory needs. These habitats provide a valuable refuge for many types of wildlife, including the osprey (*Pandion haliaetus*) which forages for fish in freshwater areas. Many upland wildlife species are seasonally dependent on wetlands, including song and game birds, opossum (*Didelphis virginiana*), raccoon (*Procyon lotor lotor*), and white-tailed deer (*Odocoileus virginianus*).

E.2 Ecological Effects

The waters of Waquoit Bay and associated freshwater ponds are exhibiting signs of water quality degradation and the diversity and abundances of key aquatic species have changed, notably during the last 30 years. In the Bay, increased phytoplankton populations have decreased water clarity and the amount of light penetrating the water. Extensive mats of macroalgae consisting mainly of the species *Cladophora vagabunda* and *Gracilaria tikvahiae*, which was unknown in the bay in 1969 (Curley et al., 1971), cover most of the bay (Valiela et al., 1992). The extent of eelgrass habitat has declined, from approximately 81 ha (200 acres) in 1950 to only 16 ha (40 acres) in 1987 (Costa et al., 1992). Eelgrass is now restricted to fragmented beds near the mouth of the bay and the tidal inlet near the mouth of the Eel River adjacent to Washburn Island, to the small salt pond and salt marshes of Washburn Island, and to small patches in Hamblin Pond, Jehu Pond, and Sage Lot Pond (Figure E-1). Physical destruction of eelgrass and saltmarsh has also occurred.

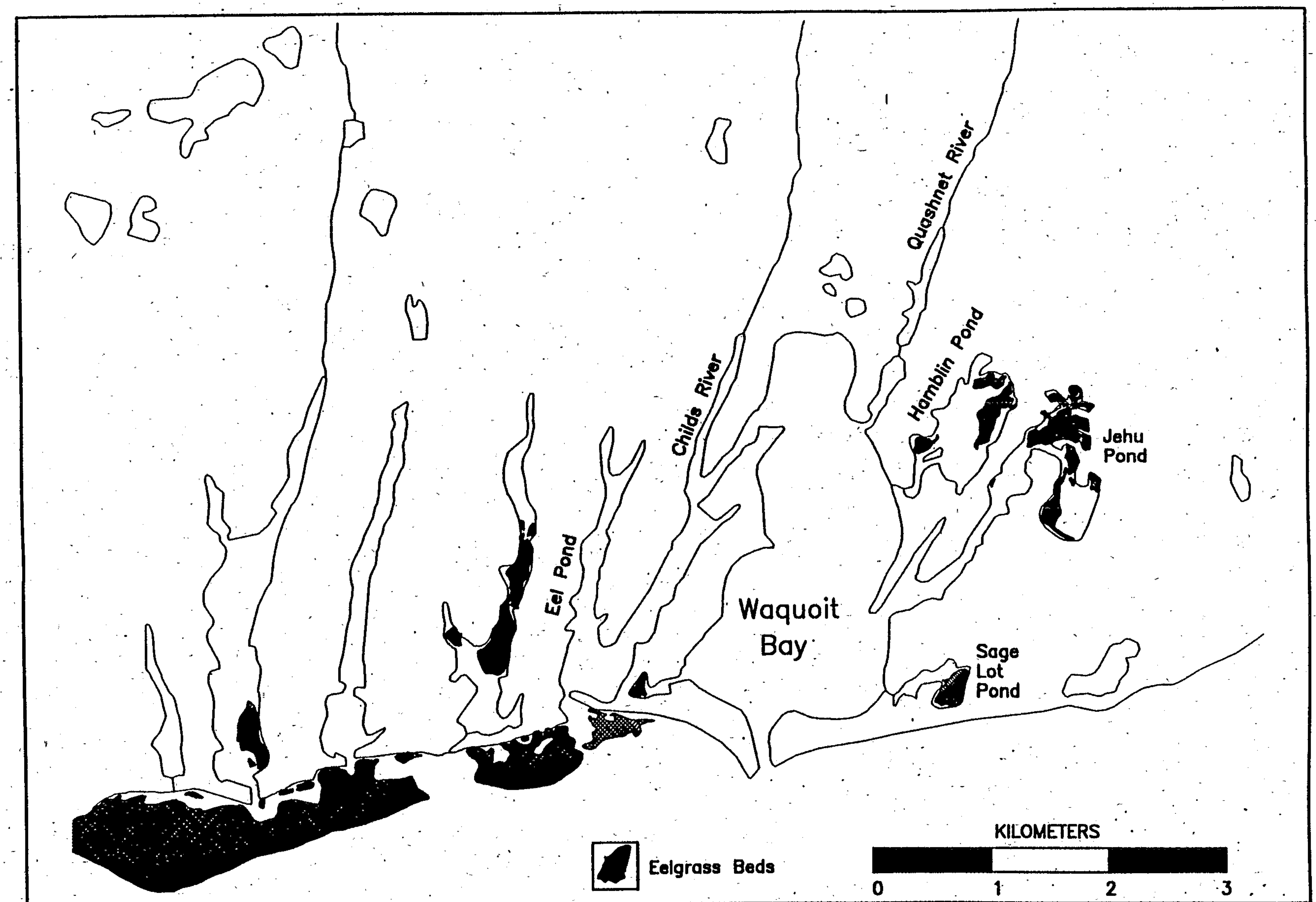


Figure E-1. Coastal area of Falmouth and Mashpee, Massachusetts, showing eelgrass beds (hatched areas) in Waquoit Bay, neighboring embayments, and Vineyard Sound, summer 1994 (M.Morton, Tetra Tech, Inc.).

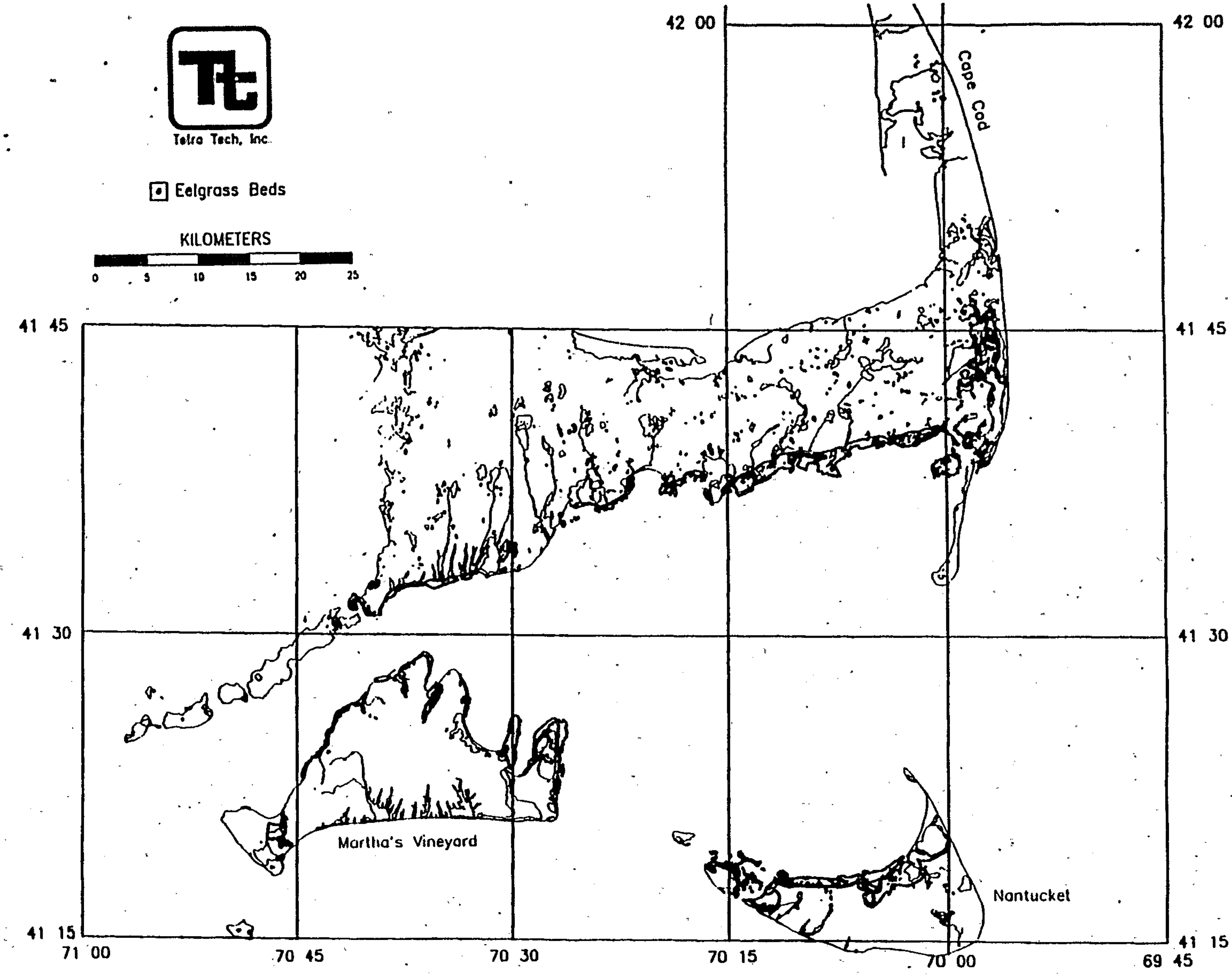


Figure E-2. Martha's Vineyard, Nantucket, and south coast of Cape Cod, showing eelgrass beds in 1994 (heavy lines). Eelgrass beds shown only from Woods Hole to Pleasant Bay and on the north coasts of Martha's Vineyard and Nantucket islands (M. Morton, Tetra Tech, Inc.).

Water clarity has also been reduced by increased sediment particulates released into the Bay, rivers, and ponds. Settling of unconsolidated particulates has adversely affected nursery and spawning habitats for fishes, as well as benthic invertebrate communities.

Alterations in the composition of species dependent on the eelgrass for nursery or adult habitat have occurred, with declining abundance of commercially important finfish, such as flounder, pollack, and hake, and shellfish, particularly the scallops. In July 1987, 1988, and 1990, fish kills occurred in Waquoit Bay and the northern beach was covered with thousands of dead winter flounder, shrimp, blue crabs, and other estuarine species (Sloan, 1992; D'Avanzo and Kremer, 1994). Anoxic conditions in the Quashnet could constitute a barrier to sea-run brook trout (McLarney, 1988). Phytoplankton blooms in Ashumet and Johns Ponds have changed the color of the water and depleted oxygen levels in the hypolimnion of the pond; fish kills occurred in Ashumet Pond in July 1985 and May 1986 (HAZWRAP, 1995).

Recent changes and reductions in stream flow have affected herring runs and trout streams (Barlow and Hess, 1993). These species require certain quantities and depths of water; for example, alewives that must travel to Johns Pond to spawn need sufficient water depth to traverse the bogs near the pond and years of low water table levels or reduced flow have limited their success.

E.3 Sources and Stressors

Seven physical, chemical, and biological stressors in the Waquoit Bay watershed were identified during discussions with the risk management team and the public. The sources of stressors include human activities within and outside of the watershed. Each stressor was characterized on the basis of its type, mode of action, and general ecological effects that might result from exposure to the stressor. In addition, information on the intensity, frequency, duration, timing, and spatial heterogeneity and extent (scale) were reviewed for each stressor in the watershed, if available. The susceptibility of the ecosystems to the stressors was also examined.

E.3.1 Sources of Stressors

Anthropogenic stressors in the Waquoit Bay watershed are the result of changing land use patterns along the coastal and upland areas (Appendix F). Land use maps produced by the Cape Cod Commission and by the LMER group identify land use with respect to commercial, cleared land and recreation, residential, agricultural, forest, wetland, mining, waste disposal and transportation. These maps also depict changing land use patterns with time. For example, in 1950 2% of the watershed was residential; in 1990 20% was considered residential (Sham et al., 1995). Land use in the watershed is primarily residential, particularly along the Childs River (McDonnell et al., 1994). In 1938, 785 houses had been built in the watershed, but more than 8000 residences were counted in the watershed by 1984. Around Waquoit Bay alone the human population has increased approximately fifteen-fold in the past 50 years, from 400 houses in 1950 to over 4000 houses in 1990 (Sham et al., 1995). More than 3000 additional single-family homes could be constructed in the watershed (Waquoit Bay Watershed Citizen Action Committee, 1992).

Cranberry bogs, the major agricultural land use, have declined over the past century; today there are less than 350 acres of bogs. Cranberry bogs, golf courses and cropland comprise 1.2 percent, 1.2 percent, and 2.0 percent of land use, respectively, in the watershed (Appendix F). The Massachusetts Military Reservation (MMR) in the northern portion of the watershed (Figure E-3) is of special concern due to the contaminant plumes emanating from ten separate point sources; this installation is the closest to an industrial or commercial land use classification in the watershed (HAZWRAP, 1995).

Although the Quashnet River has been recognized by some as an extremely valuable resource, development pressure continues to build in the surrounding towns of Mashpee and Falmouth and with it the search for additional sources of drinking water. To restrict one proposed housing development, the Commonwealth of Massachusetts purchased 146 ha (361 acres) of land along the river, thereby limiting this housing development to 185 units without river frontage (Baevsky, 1991). Ashumet and Johns Ponds also face potential susceptibility to development pressure. The watershed is particularly susceptible to buildup of nutrients and chemical pollutants because of the porous soils of the watershed and the limited flushing of waters from the ponds and the Bay (from a few months to over 30 years). Development in the watershed has also increased human activities in and on the surface waters, particularly in the ponds and bay. Stressors associated with atmospheric deposition might also contribute to those already present from the various land and marine uses.

Residential Development. Activities in the watershed associated with residential land use that might add to nutrient-loading within the ecosystem include on-site septic systems; fertilizer use on lawns, golf courses, and gardens; and housing and road construction with the attendant increase of impervious surfaces (Valiela and Costa, 1988). Each of the 8000 homes in the watershed has an on-site wastewater disposal (septic) system that contributes nitrogen to ground water which travels to Waquoit Bay. Wastewater is a larger contributor of nitrogen to the estuary than is atmospheric deposition or fertilizers (Valiela et al., 1996). Fertilizer inputs to Waquoit Bay are primarily from residential lawn applications. Shellfish beds are frequently closed at the mouth of the Quashnet River to protect consumers from potential exposure to human pathogens that are not trapped by septic systems or soil and reach the bay. Pesticide applications on golf courses, cranberry bogs, and lawns add toxic chemicals. Private and municipal well development alters ground water flow regimes. Housing and road construction also are sources of sediments as construction uproots vegetation and roads and driveways increase impervious surface cover. Oil hydrocarbons and other chemicals can accumulate on impervious surfaces like parking lots and roads and be washed off by rain to enter ground and surface waters.

Industrial Uses. MMR, composed of Camp Edwards and Otis Air Base, is located on the upper western portion of Cape Cod and covers 8903 ha (22,000 acres). Past industrial and military activities at MMR have mobilized chlorinated solvents and fuel constituents forming plumes of contaminated ground water. MMR was added to the National Priorities List (NPL) on November 21, 1989 (HAZWRAP, 1995). Sewage treatment facilities at MMR and increased runoff from impervious surfaces add nutrients; well development might have altered ground water flow (Barlow and Hess, 1993). Ashumet Pond is receiving its greatest input of phosphorous from the MMR sewage treatment plant (STP). If phosphorous levels continue to remain as predicted over the next ten years, Ashumet Pond will become eutrophic. Freshwater ponds could also be affected by other contaminants associated with MMR (HAZWRAP, 1995).

Agricultural Activities. Agricultural practices are sources of nutrients via fertilizer application and runoff from animal wastes. Other agricultural activities that affect the ecosystem are the addition of pesticides or herbicides, which can be toxic to aquatic life and water-dependent wildlife, and the construction and use of flow control structures at Johns Pond for irrigating the cranberry bogs along the Quashnet River, which can alter flow patterns, change the quantities of surface water in the ponds and streams, and add to sediment-loading. Migration of pesticide and other chemical constituents from an abandoned cranberry bog in the watershed could also contribute chemicals to surface and ground waters (HAZWRAP, 1995).

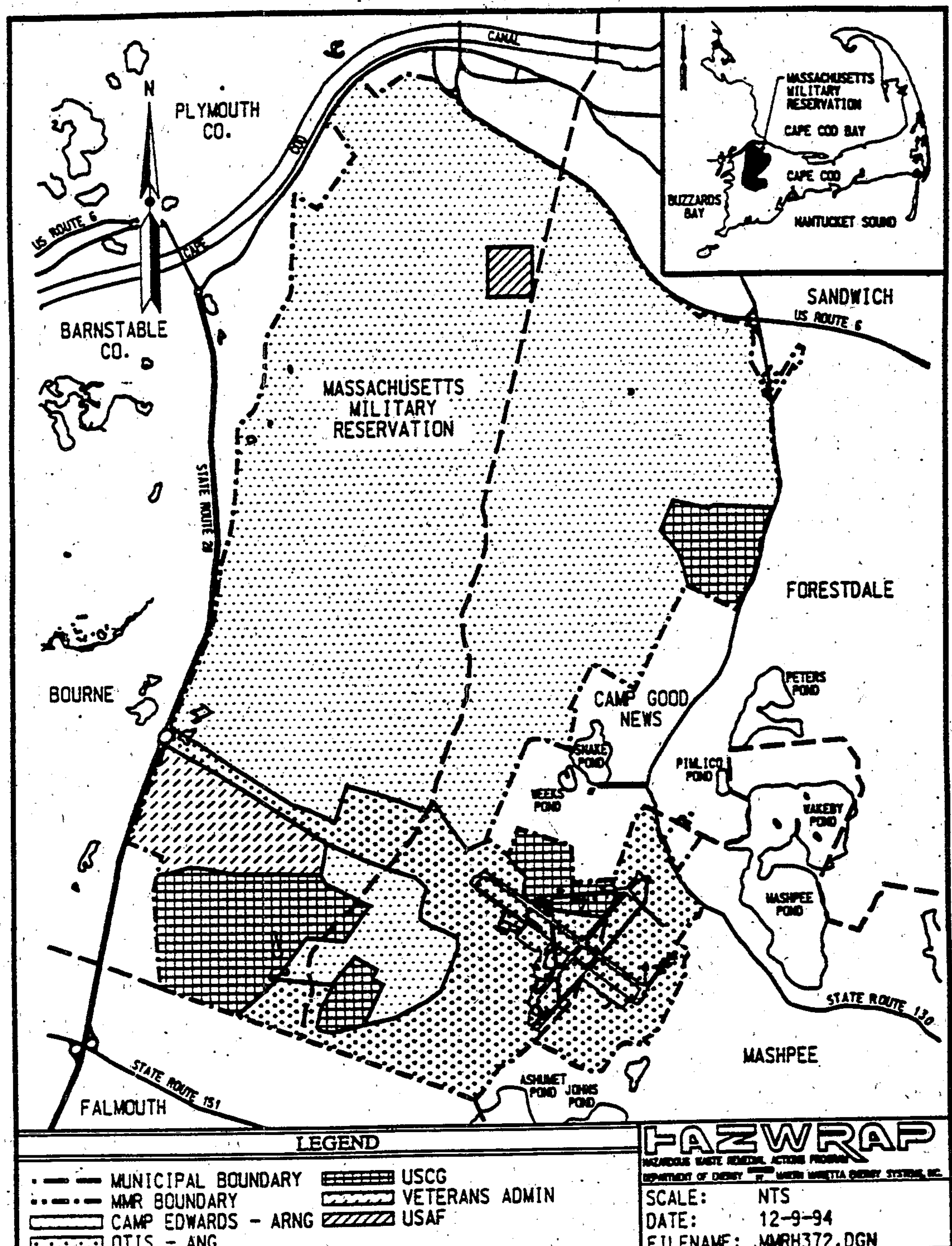


Figure E-3. Location of the Massachusetts Military Reservation, North of Johns and Ashumet Ponds (HAZWRAP, 1995).

Aquatic Activities. Water-based activities also are sources of stressors to the estuarine and freshwater ecosystems (Waquoit Bay Watershed Citizen Action Committee, 1992; HAZWRAP; 1995; WBNERR, 1995). These activities include recreational boating, which is a source of nutrients and human pathogens from on-board septic systems and toxic chemicals from leaching of antifouling paint chemicals from boat hulls and spills of fuel and other discharges from marinas; construction of docks and piers using lumber treated with heavy metals and other wood preservatives or antifouling compounds, which can introduce toxic chemicals to the estuary (Figure E-4); waterway maintenance, including dredging and shoreline modification, which adds resuspended sediments; shellfishing in the estuary, which damages eelgrass habitat, resuspends sediments, and contributes to harvest pressure; recreational fishing in the estuarine, riverine and pond environments, which contributes to harvest pressure; and swimming in the Bay and Ashumet and Johns Ponds, which can disrupt benthic communities and resuspend sediments. More than 2100 boats greater than 6.1 m (20 ft) in length are estimated to use the Bay and rivers (Waquoit Bay Watershed Citizen Action Committee, 1992), with an unknown number of smaller vessels using the estuary and Ashumet and Johns Ponds.

Activities Outside of the Watershed. Several land and water use activities are not local or can interact with local sources of stress. Armoring of the coast outside of the watershed changes sediment deposition patterns along the barrier beaches of Waquoit Bay. Offshore fishing depletes the stocks of commercially valuable species such as winter and summer flounder, pollack, striped bass and bluefish. Wet and dry atmospheric deposition of nutrients and toxics can have sources within and outside of the boundaries of the watershed. Automobiles, lawn mowers, and motor boats generate NOx's locally. These atmospheric gases also originate in coal-fired plants hundreds of miles from the watershed. Nitrogen-containing atmospheric deposition adds nutrients to the watershed (Valiela and Costa, 1988). Other toxic chemicals and metals can be adsorbed to particulates from coal-fired plants, incinerators, and automobile exhaust fumes, settling in the watershed. Mercury is a toxic chemical that also originates outside the watershed but is deposited in the watershed where it can be methylated and accumulate in tissues of fishes and piscivorous wildlife (reviewed in Facemire, 1995; Fitzgerald, 1995; Hurley, 1995; and Weiner, 1995; HAZWRAP, 1995).

E.3.2 Stressor Characteristics

Altered flow, sediment, physical destruction, nutrients, toxic chemicals, eelgrass disease, and fisheries harvesting were identified as the major stressors affecting the ecological resources of Waquoit Bay watershed.

Altered Flow (Riverine). Hydrologic modification is a physical stressor that results in altered stream flow patterns and reductions in the quantity of fresh water in surface waters. Anadromous and catadromous finfishes need sufficient water depth to traverse the shallow Waquoit estuary and streams; sufficient fresh water is needed to sustain certain estuarine species that require reduced salinities and prevent saltwater incursions in the ground water (Day et al., 1989; Milham and Howes, 1994). Changes in the hydrology of the Waquoit Bay watershed can be sporadic, depending on precipitation patterns, especially the number and intensity of hurricanes or northeasters versus periods of drought, as well as seasonal requirements for irrigation of cultivated crops. Long-term reductions in ground water occur from municipal wells that supply drinking water to the residents from the western lens of the Cape Cod Aquifer.

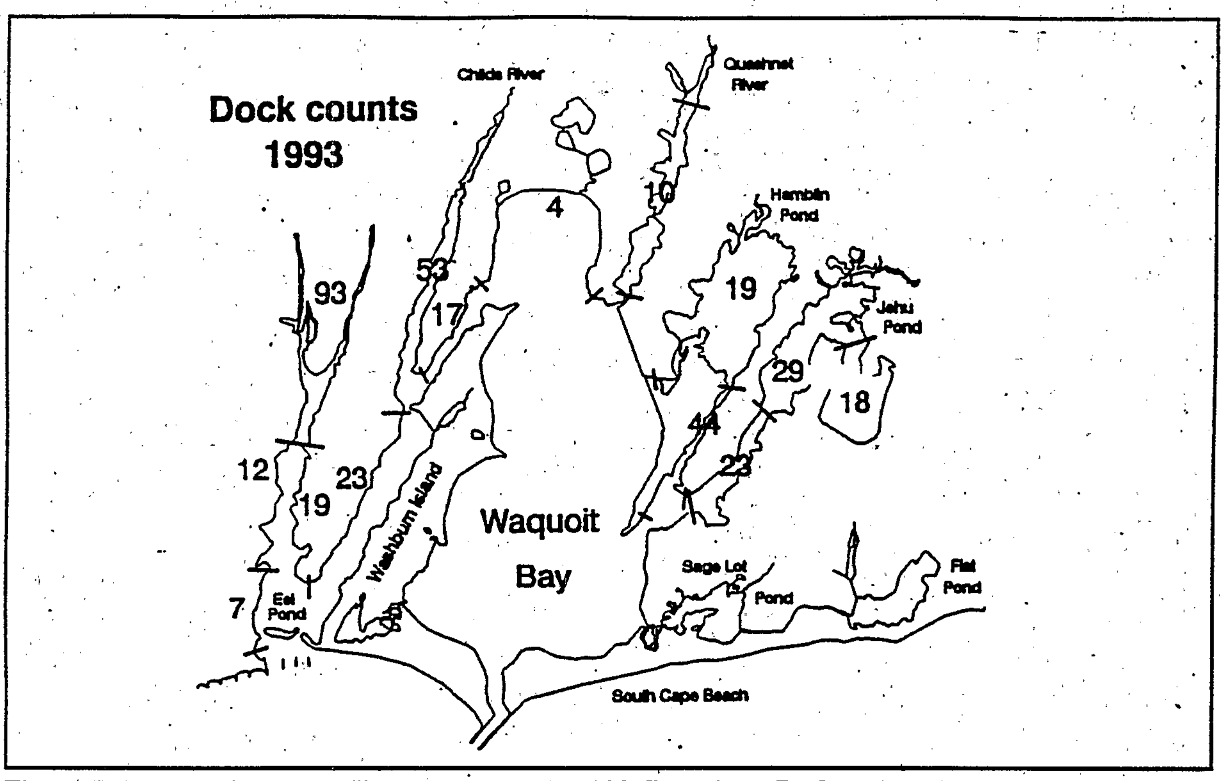


Figure E-4. Dock Counts in Waquoit Estuary in 1993 (Data from R. Crawford, WBNERR).

Around the turn of the century, cranberry bogs were developed along the upper Quashnet River and water flowing out of Johns Pond was controlled to provide water to the bogs as needed, particularly in the fall for harvesting the cranberries. This land use altered the flow volume, velocity, and path of the river resulting in loss of spawning habitat for anadromous fish species. Cranberry bogs are often flooded in winter to prevent freezing and the water is then released in the spring. While the spring release might counteract the effect of groundwater withdrawals, the harvest flood waters are often released during the time of autumn spawning for trout (USGS, 1991). An extensive effort by Trout Unlimited and the Massachusetts Department of Fisheries and Wildlife has restored major sections of the trout habitat, although some species have not been restored. Alewives and blueback herring that swim to Johns Pond to spawn also need sufficient water depth to traverse the bogs near the pond. Cranberry cultivation could be increasing at the headwaters of the Quashnet in the near future.

In addition, the Quashnet and the ground water that feeds it are currently under pressure from urban development (Barlow and Hess, 1993). Plans to develop a community drinking water well could further alter flows and affect the ground water system (Barlow and Hess, 1993), including thermoregulation of the temperature of spawning beds in the rivers, which protect the eggs of some fish species. Longitudinal, lateral, and vertical changes in salinity patterns in the upper bay could have affected the distribution of some estuarine fauna and flora (e.g., Schroeder, 1978; Welsh et al., 1978; Day et al., 1989). Dredging activity in the channels leading into Waquoit Bay changes water flow patterns and flushing rates between Waquoit Bay and Eel Pond, as well as the smaller ponds (Aubrey et al., 1993). Changes in current patterns can lead to shoaling near the inlets to the bay, primarily from flood deltas and secondarily from ebb deltas, that in turn affect current patterns (Geyer and Signell, 1992; Fitzgerald, 1993).

Sediment. Terrigenous and biogenic particles accumulating in aquatic ecosystems from land runoff, erosion, and biological productivity are another physical stressor. Sediment can be easily disturbed by currents, wave action, or organism movements, suspending particles in the water column. The particle load is referred to as turbidity, which decreases light penetration through the water, and the fine particulates can interfere with feeding and respiration in benthic and pelagic aquatic organisms and feeding in visual predators. Particles can remain in suspension as long as the velocity of the water is sufficient to counteract gravitational forces. As water velocity decreases, sediment particles settle, with heavier particles settling first; for example, swift flowing streams can carry a higher sediment load that is then deposited when the stream empties into a slower-flowing river or bay. Thus, fine-grained sediments are more likely to remain in suspension longer, resulting in increased turbidity. When the particles settle to the bottom, deposition on surfaces of sedentary plants and animals, as well as the bottom, can cover organisms that might have a difficult time removing the particles and alter habitat features, for example, changing gravel bottom to mud (NRC, 1992).

Changes in sediment loading and deposition in the watershed occur frequently, in concert with changes in precipitation, surface water volumes, wind- or water-driven current patterns, and construction or other human activities. Acute changes in sedimentation can occur after catastrophic natural storms such as hurricanes (Hayes, 1978) and after dredging or construction activities; chronic increases in sedimentation result as sediments are resuspended by currents in shallow areas. Swimming and burrowing activities of aquatic organisms can also influence sediment deposition and resuspension (e.g., Yingst and Rhoads, 1978). Resuspended sediments can reintroduce adsorbed nutrients and toxics to the water column.

The quantity of sediment entering the surface waters of Waquoit Bay watershed from runoff and rivers is unknown. Runoff is not thought to be a problem, since water readily percolates through the sandy soil. Reductions in streambed permeability might occur if fine-grained sediments deposit in spawning areas of the rivers (Baevsky, 1991), limiting gas exchange from the eggs with the surrounding water. Increased turbidity from suspended and resuspended sediments has reduced light levels needed for photosynthesis by eelgrass in Waquoit Bay, although eelgrass could grow, slowly, at 10 percent of surface light intensity (Short et al., 1989; Giesen et al., 1990). Sediment particles also increase the potential stress on eelgrass because epiphytes growing on eelgrass blades are good depositional surfaces for suspended sediments (Horne et al., 1994). Suspended sediments might also weight down the eelgrass blades causing them to sink to the bottom where they can die from insufficient light or suffocation (Kemp et al., 1993; Short, 1989).

Protecting the coast from erosion by building of jetties and groins has several effects on estuarine habitats. Jetties and groins alter regional sand and other sediment transport and sedimentation patterns (WBNERR, 1995). These alterations can have a negative impact on barrier beaches, salt marshes, and eelgrass beds, all habitats for estuarine or water-dependent wildlife. Shoaling near inlets to the bay has occurred from dredging, also changing sedimentation patterns (Fitzgerald, 1993). These activities might also adversely affect eelgrass beds in lower Waquoit Bay.

Loss of eelgrass, in turn, also can change sediment depositional patterns since eelgrass beds enhance sediment deposition (Short, 1984; 1989). The distribution and abundance of many benthic organisms can be adversely affected by sediment deposition. For example, softshells or steamers grow best in fine muddy sediments, but they are more susceptible to predation in these habitats (Funderburk et al., 1991). Siphon-clogging problems might occur in mud substrata which can offset rapid growth rates in these sediments (Emerson et al., 1988). Hard clams or quahogs grow best in sandy sediments, since higher water currents provide more food to these suspension feeding organisms (Rice and Pechenik, 1992). Juvenile quahogs lack extensible siphons and attach to sand grains with byssal threads to permit them to feed at the sediment surface. Despite this affinity for sandy to muddy sand sediments, adult quahogs are found in a variety of sediment types, with gravely sediments providing protection from predators. The thick shell, lack of shell gaping, and benthic burrowing limit the predation on these clams. It is not known whether changes in the composition of the substratum have altered community structure to increase shellfish predation.

Physical Destruction. Direct and indirect alteration of habitat structure is a physical stressor that results in changes to the physical, chemical, and biological conditions that support the survival, growth, and reproduction of different species of plants and animals in a community. In addition to hydrologic modification, changes in current and flow patterns, and increased sedimentation, several other mechanisms can alter the estuarine habitat in the Waquoit Bay watershed, with subsequent effects on the organisms (Day et al., 1989). These activities occur sporadically; the changes in conditions brought about by physical destruction can be short- or long-term, but restoration of the habitat to its structure and function prior to destruction might be impossible (NRC, 1992).

Shading by docks built from shore into the estuary, particularly in Great River, a tributary of Waquoit Bay, decreases light penetration, adversely affecting eelgrass (Burdick and Short, 1995). This is not considered a major stressor on eelgrass or other aquatic life in Waquoit Bay, however, since the area covered by docks is small–less than 1 percent of the surface water area in Waquoit Bay, its tributaries, and ponds (WBNERR, 1995). Mechanical disruption from clam digging, boat props, and moorings can cut eelgrass blades or uproot eelgrass plants resulting in death of eelgrass itself. Habitat fragmentation from these activities affects organisms that reside in eelgrass meadows. On land, construction of roads near the estuary can stop the landward progression of salt marshes with deleterious effects on inhabitants.

Nutrients. Nearshore waters worldwide are receiving increased releases of nutrients, particularly nitrogen, from coastal watersheds (e.g., Nixon et al., 1986; Valiela et al., 1990; USEPA, 1994). Eutrophication, especially nitrogen enrichment in estuarine ecosystems and phosphorus enrichment in freshwater ecosystems, has been implicated as a major cause of phytoplankton and nuisance macroalgal blooms (Day et al., 1989; Batiuk et al., 1992; NALMS, 1992). Inorganic nitrogen and phosphorus, primarily in the form of nitrate and phosphate, are essential for the growth of photosynthetic algae and plants, in addition to inorganic carbon, silicon, and other compounds (reviewed in Goldman, 1974, and Day et al., 1989). In the aquatic environment, nitrogen is converted to various forms through complex biogeochemical cycles that reduce or oxidize the elements or transform organic compounds to inorganic states, including decomposition and excretion (of organic forms, ammonium, and phosphate), bacterially-mediated nitrogen fixation (reduction of inorganic nitrogen to ammonium), nitrification (oxidation of ammonium to nitrate), and denitrification (conversion of nitrate to nitrogen gas by anaerobic processes). Phosphorus is cycled through dissolved inorganic phosphorus, particulate organic phosphorus, and dissolved organic phosphorus states involving plants and complexation with metals in sediments. Plants assimilate nutrients and produce biomass by various biochemical reactions during photosynthesis and these reactions are driven by the quantities of nutrients available until they are saturated; usually the concentration of one or more nutritional substances is less than its saturation level, limiting photosynthesis and plant growth. Day et al. (1989) noted that aquatic plants have adapted to the average nutrient concentrations to which they have been exposed.

As noted above, the sources, pathways, and fate of anthropogenic nitrogen are related to land use patterns and in part to local and regional geology. Much of the nitrogen is believed to be attenuated during passage through the Waquoit Bay watershed via volatilization, uptake by flora and fauna, adsorption, and denitrification (see Rhodes et al., 1985; Nixon and Lee, 1986; Seitzinger, 1988; Reddy et al., 1989; WBNERR, 1993). The porous, sandy soils of this watershed promote rapid percolation of precipitation with the result that there is little run-off from surface sediments (Strahler, 1968; Valiela et al., 1990; Oldale, 1992). Thus, nitrogen, added either by precipitation or dry deposition, rapidly enters the ground water and can travel to Waquoit Bay (Figure E-5). In a like manner, septic system and fertilizer additions of nitrogen and phosphorus also penetrate the soil and make their way to the ground water and to Waquoit Bay (Valiela et al., 1996). Microbial decomposition of biogenic material and direct excretion by animals into the ponds, rivers, and estuary are biological sources of nutrients. These processes interact with chemical processes occurring in the water column and sedimetns related to oxidation and reduction of the nutrients to increase or decrease the quantities and forms of nutrients available in the Waquoit Bay watershed (HAZWRAP, 1995).

Ground water concentrations of nitrogen are higher in more developed areas on Cape Cod than in less developed areas (Figure E-6) (Persky, 1986). In the Waquoit Bay complex, subwatersheds can be identified which have experienced different rates of nutrient loading due to different patterns of land use. Ground water concentrations of nitrogen are higher in the more developed than in the less developed subwatersheds (Table E-2) (Valiela et al., 1992; Rudy et al., 1994). Different ratios of dissolved organic nitrogen (DON) to dissolved inorganic nitrogen (DIN) were found in the ground water of the Waquoit Bay watershed, with the most urbanized subwatershed, the Childs River, having a ratio of 1:2, and the least urbanized, Sage Lot Pond, having a ratio of 7:1 (Rudy et al., 1994). DON also appears to be influenced by the presence of salt marsh, creating anoxic ground water and increasing the accumulation of DON. Ground water travels at the rate of 13 feet per day in the watershed. Houses built very close to the shore have the greatest impact on nitrogen loading to the bay. Year-built data and proximity to shore data show that nearshore areas were developed first and are the most densely developed (Sham et al., 1995).

Table E-2. Nitrogen Levels in Groundwater of the Childs River Subwatershed Compared to that of Sage Lot Pond.

Nitrate Concentration in μm		
Measurement	Childs River	Sage Lot Pond
Maximum	736.38	29.24
Average	440.85	13.15
Minimum	162.81	2.6

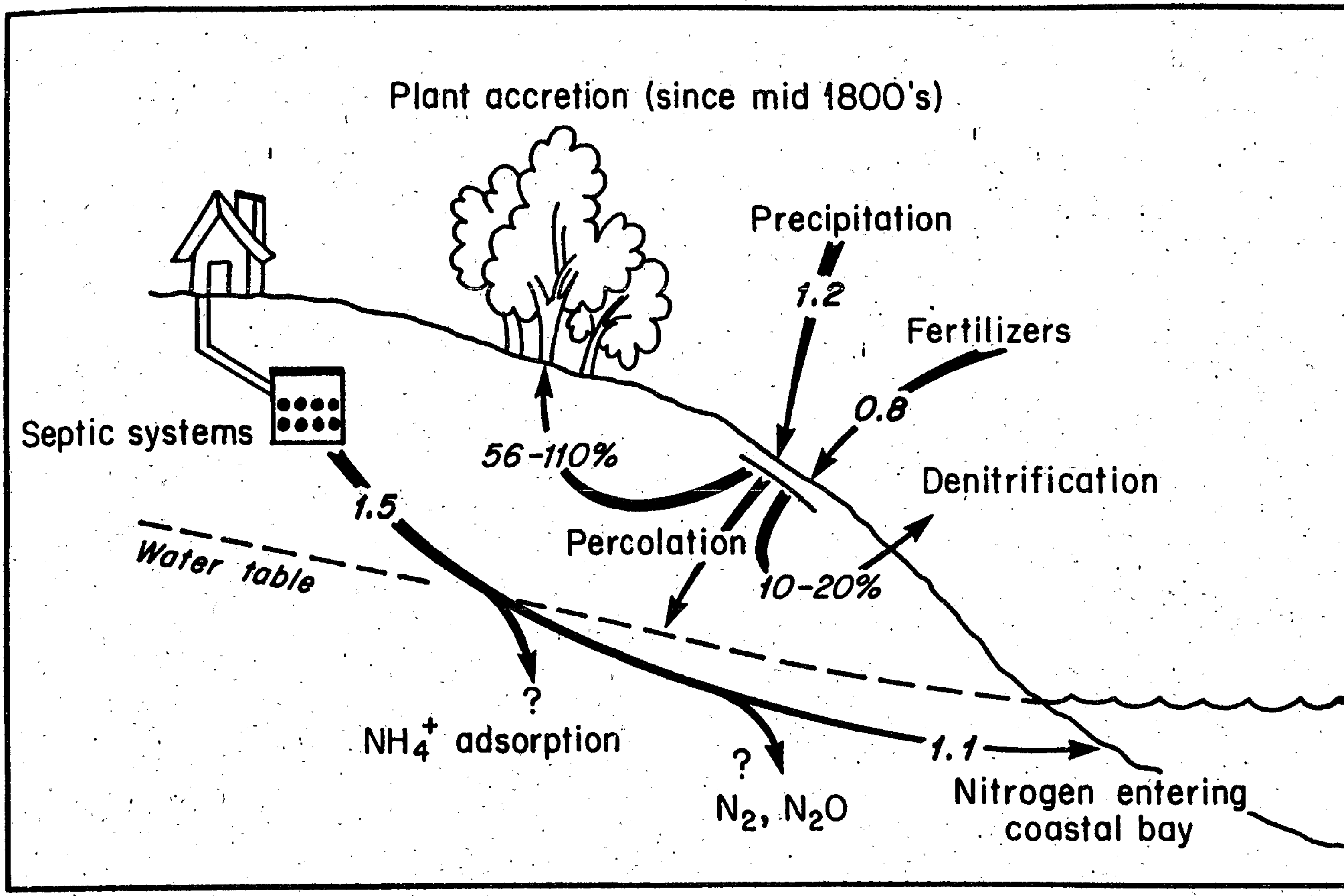


Figure E-5. Inputs and fate of nitrogen (mol N x 10^6 yr^{-1}) entering the watershed and traveling toward Buttermilk Bay near Waquoit Bay. Additional sources not shown are precipitation directly onto surface waters and onto impervious surfaces that are washed into surface waters. (Reprinted from "Couplings of Watersheds and Coastal Waters: Sources and Consequences of Nutrient Enrichment in Waquoit Bay, Massachusetts," by Valiela et al., published in *Estuaries*, December 1992, Vol. 15, No. 4, pp. 443-457, with permission from *Estuaries*. ©Estuarine Research Federation.)

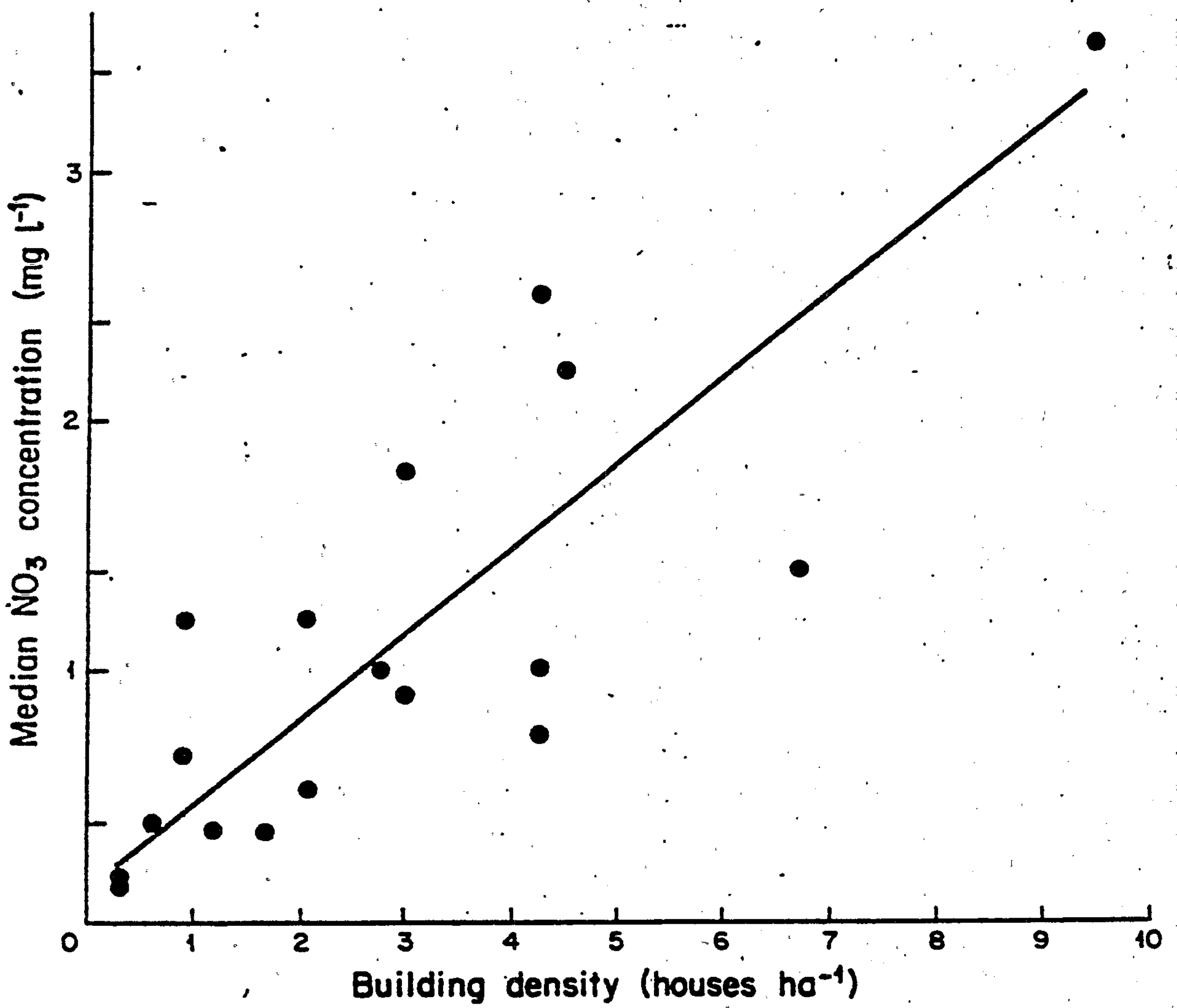


Figure E-6. Nitrate concentrations in ground water below areas of Cape Cod having different densities of buildings, based on data from Persky (1986). (Reprinted from "Couplings of Watersheds and Coastal Waters: Sources and Consequences of Nutrient Enrichment in Waquoit Bay, Massachusetts," by Valiela et al., published in *Estuaries*, December 1992, Vol. 15, No. 4, pp. 443-457, with permission from *Estuaries*. ©Estuarine Research Federation.)

Residential septic tanks could also be responsible for the additional input of naturally occurring nutrients such as phosphorus and nitrogen into both of the freshwater ponds. The MMR STP plume has been identified as the primary source responsible for increased levels of phosphorous to the ground water discharging into Ashumet Pond (HAZWRAP, 1995). Since 1936, the disposal of treated sewage from MMR has been accomplished through infiltration beds to a sand and gravel aquifer, creating a plume of contaminants 914 m (3,000 ft) wide, 23 m (75 ft) deep, and more than 3353 m (11,000 ft) long, including high levels of sodium, chloride, nitrogen, detergents, and other sewage-related compounds (LeBlanc, 1984; LeBlanc et al., 1991). Fate and transport of contaminants in these plumes has proven very difficult to evaluate due to the influence of the two large kettle hole ponds, Ashumet and Johns Ponds, on ground water flow. Contaminants appear to be both discharging to the ponds and migrating under the ponds. The USGS is currently evaluating the current and future impacts of phosphorus on Ashumet Pond; the concentrations of phosphorus in the hypolimnion are higher in Ashumet Pond than Johns Pond, but preliminary studies suggest that phosphorus might not be limiting here (Table E-3) (HAZWRAP, 1995). The Quashnet River and Waquoit Bay are potential future locations for ground water discharge of MMR plume contaminants in the absence of remediation.

Atmospheric NO_3 and SO_x deposition are either directly deposited to surface waters or are transported in terrestrial runoff and drainage into ground water. The latter transport pathways threaten to lower pH levels in the Quashnet River and other surface water- or ground water-fed streams in the watershed because there is very little natural buffering capacity in the glacial soils. The pH of the Quashnet is in the range of 6.0 to 6.4, which is not in the optimum range for brown and brook trout and does not meet the Massachusetts Surface-Water Quality standards of 6.5 to 8.0 for Class B streams (Baevsky, 1991). The major limitation for assessing the potential ecological effects of nutrients on the Quashnet River is the paucity of available data.

Conversely, ecological effects of nutrients in the ponds and the bay have been extensively studied. Phytoplankton blooms have appeared in these ecosystems (HAZWRAP, 1995; WBNERR, 1995). Increased phytoplankton productivity decreases light penetration, altering the light regime for submerged aquatic vegetation (Batiuk et al., 1992). Macroalgal mats, consisting of the fast-growing species *Cladophora vagabunda* and *Gracilaria tikvahiae* are present in the shallow bay bottom adjacent to highly developed land areas, particularly the lower Childs and Quashnet Rivers (Table E-4). Epiphytes have grown on eelgrass blades (Valiela et al., 1992; Peckol et al., 1994), leading to reductions in the size of eelgrass patches in the bay (Orth and Van Montfrans, 1984; Costa, 1988; Burkholder et al., 1992; Short et al., 1992; Valiela et al., 1992; Boxhill et al., 1994; Hurlburt et al., 1994). Nutrients might not be the only factors influencing phytoplankton and macroalgal growth in the ponds and bay, since altered/low ground and surface water flow, changes in the distribution and abundance of herbivores, and light penetration (which changes daily and seasonally) could also affect the abundance and distribution of key aquatic flora (reviewed in Cambridge and McComb, 1984; Cambridge et al., 1986; Day et al., 1989; Neckles et al., 1993; Boxhill et al., 1994).

Table 3. Nutrient loading from the Massachusetts Military Reservation. N + P data extracted from Figures 7.26 through 7.29, Volume II (HAZWRAP, 1995). Biology data extracted from pages 79-80, Volume I, and Figures 7.24 and 7.41m volume II (HAZWRAP, 1995).

	Nutrients					Biology (Phytoplankton)	
Site	Total DIN μg-N/L	NH_4 μg-N/L	NO_3 μg-N/L	SRP μg-P/L	TSP μg-P/L	Number of cells/ml	mg fresh wt./m^3
November 1992							
Johns Pond	~60	~10	~50	~0.5	~2.5-6	~3000	81-622
Ashumet Pond	~40	~3	~38	~1	~7-10.5	~3000	2447-7939
April 1993							
Johns Pond	< ~67	<5-57	<10	<1	~2.8-5.6	11,000-22,000	1100-3800
Ashumet Pond	~750	<5	~750	<1	~2	20,000-78,000	1100-3800
June 1993							
Johns Pond epilimnion	40-70	20-40	20-30	~0.5	~1.5	3500-9200	300-2250
Johns pond hypolimnion	70-460	40-460	<5-120	0.5-5	1.5-15	200-1000	75-45
Ashumet Pond epilimnion	~80	~30	~50	~0.5	~10	100-5600	~25-200
Ashumet Pond hypolimnion	~80-630	~30-630	~50	0.5-237	10-180	100	<25
August 1993							
Johns Pond epilimnion	<30	<10	<20	<0.5	2.5-4	4800-37,000	220-4800
Johns pond hypolimnion	40-730	10-770	0-30	0.5-4	4-14.5	2000-11,000	100-300
Ashumet Pond epilimnion	<20	<20	0.00	0.00	<5	4800-35,000	100-1300
Ashumet Pond hypolimnion	0-860	0-860	0-40	0-380	5-275	~2000	<100

Table E-4. Nitrogen loading to water table, chlorophyll concentrations, and mean (± standard deviation) biomass of macrophytes in three selected subestuaries of Waquoit Bay. (Adapted from Valiela et al. 1992.

Subwatershed	N loading to water table (kg N yr^{-1})	Chlorophyll concentrations at mouth (mg m^{-3})	Total macroalgal biomass (g m^{-2})	Eelgrass biomass (g m^{-2})
Childs River	14209	25.5 ± 7.6	335 ± 39.8	0
Quashnet River	14534	5.9 ± 1.7	150 ± 14.3	0
Sage Lot Pond	331.5	3.9 ± 1.2	90 ± 12.1	117 ± 12.6

Finfish and shellfish are at indirect risk from effects of nitrogen loading. Macroalgal mats provide poorer quality finfish habitat than eelgrass beds for many resident finfish and for young-of-the-year part-time resident finfish (WBNERR, 1995). Small fish can become trapped in the tangle of algal filaments (Sloan, 1992). Although photosynthesis by the algae on sunny days replenishes the oxygen, continuous cloud cover for several days can produce hypoxic or anoxic conditions under the algal mats and send fishes into shallows where dissolved oxygen levels are higher (Valiela et al., 1992). Johns Pond is classified as oligotrophic/borderline mesotrophic; Ashumet Pond is classified as mesotrophic and the hypolimnion becomes oxygen deficient as a result of increased decomposition during summer stratification (Ashument Pond Trophic State and Eutrophication Control Assessment Report, 1987, cited in HAZWRAP, 1995). Fish kills occurred in Ashumet Pond in July 1985 and May 1986. Mass mortalities of finfish and shellfish occurred in the upper reaches of Waquoit Bay during July 1987, 1988, and 1990. Valiela et al. (1992) also noted that reduced photosynthetic activity by the macroalgal mats resulted in higher nutrient concentrations in the water column followed by a bloom of phytoplankton during a July 1988 prolonged overcast period. Preliminary measured rates of gross phytoplankton production and gross ecosystem production in the lower Quashnet River varied with time and decreased in response to a complex suite of physical factors (Harrison et al., 1994).

The benthic faunal community is affected by nutrient enrichment in two ways. First, hypoxic and anoxic bottom water resulting from increased algal and microbial respiration, particularly during cloudy days and nights in summer months, can produce physiological stress and cause mortalities in benthic community organisms (D'Avanzo and Kremer, 1994). All life stages of hardshell clams appear to be susceptible to low dissolved oxygen levels in the water, with growth rates of larvae being reduced below 4 mg/L dissolved oxygen (Funderburk et al., 1991). Adult clams can tightly close their shells and respire anaerobically in anoxic bottom sediments in order to withstand these episodic events, but they generally fare better when dissolved oxygen levels in the overlying water exceed 5 mg/L (Funderburk et al., 1991). Second, although hard and soft clam growth rates from cleared bottom areas can increase in response to higher nutrient inputs and increased phytoplankton production (Chalfoun et al., 1994; Harrison et al, 1994), loss of eelgrass beds creates a loss of habitat that provided shelter, refuge and a food source for many fishes and invertebrates (Valiela et al., 1992). Other changes in estuarine benthic communities have also resulted from eutrophication. (Frithsen, 1991). Invertebrate species abundance and diversity is lower in areas without eelgrass in Waquoit Bay (Valiela et al., 1992).

The loss of eelgrass appears to be directly related to the success of scallop larvae. The bay scallop larvae attach by byssal threads to eelgrass blades and the small juvenile scallops tend to move up the eelgrass blade to escape benthic predation by crabs, starfish, oyster drills and whelks (Pohle et al., 1991; Garcia-Esquivel and Bricelj, 1993). Byssal thread attachment by juveniles is reversible and dynamic, allowing the young scallops to keep pace with the growth of the eelgrass blades, which turn over rapidly during the summer. Rapid growth of juvenile scallops occurs during this attached phase that can last a couple of months (Pohle et al., 1991). This stage is followed by descent to the sediments at the base of the blades, at which time an epibenthic existence without byssal thread attachment occurs. Adult bay scallops can occur in eelgrass beds or over bare sandy substrate (Garcia-Esquivel and Bricelj, 1993). Heavy predation by mud crabs (*Dispanopeus sayii*), green crabs (*Carcinus maenas*), spider crabs (*Libinia* sp.), and mobile predators (northern puffer *Sphaeroides maculatus*) and brachyuran crab (*Ovalipes ocellatus*) occurs on the small, epibenthic scallops which have shells and are incapable of complete or provalve closure (Garcia-Esquivel and Bricelj, 1993). Thus, scallop populations tend to be limited by predation on the attached larvae/small benthic juveniles and water quality affects the pelagic larvae (MacKenzie, 1989).

Toxic Chemicals. The biota of the watershed could be exposed to potentially toxic and bioaccumulative chemical contaminants. Toxic substances are materials that are capable of producing an adverse response in a biological system, altering or impairing its structure or function or producing death (Rand, 1995). Toxics can affect the induction or inhibition of enzymes and/or enzyme systems within the cell, in turn altering the functions of these enzymes. Enzyme dysfunction leads to disruption of metabolic processes including, but not limited to, phosphorylation, uptake, or detoxification reactions, which is reflected in reduced/increased production of cellular constituents, changes in cell cycling and replication, and degeneration of cellular and nuclear membranes. Effects produced by toxic chemicals are dependent on the concentration of the chemical and duration of exposure, as well as the type of chemical, its fate and transport in the environment, and other factors. Sublethal effects of toxics include changes in behavior, growth, development, and reproduction of individuals, that ultimately affect the relative distribution, abundance, and physiological condition of populations within aquatic communities. Genotypic and phenotypic factors operating within individuals affect their susceptibility to different toxicants and ability to metabolize the chemical to produce other compounds of reduced or greater toxicity. Some compounds, particularly the more hydrophobic/lipophilic ones, are not readily broken down in the environment or by organisms and accumulate in the fatty tissues. Toxic effects then occur when the concentrations of compounds are relatively high or the chemicals are released when fats are metabolized, as during starvation.

The majority of the information concerning toxic chemicals in the Waquoit Bay watershed is focused on the contribution of contaminated ground water emanating from the MMR (HAZWRAP, 1995). Johns Pond and Ashumet Pond are located south of MMR and are subject to potential contaminated ground water flow from the main industrialized portions of the base including flightline and fueling areas, and open storm drainage ditches. Water moving down through soil contaminated by past industrial and military activities at MMR has mobilized chlorinated solvents and fuel constituents forming plumes of contaminated ground water. Several of these plumes are migrating within the Waquoit Bay watershed (Figures E-8 and E-9). Several study sites or areas of concern (AOC) are under investigation north of the ponds and the plumes could potentially affect both human and ecological receptors. These sites include: Fire Training Area 2/Landfill-2 (FTA-2/LF-2), the Petroleum Fuel Storage Area (PFSA), and Storm Drain-5 (SD-5) (HAZWRAP, 1995). For purposes of this investigation,all of the above described plumes within the Waquoit Bay watershed have been grouped together as the Southeast Regional Ground Water Operable Unit (SERGOU). SERGOU plumes originate from FTA-2/LF-2, PFSA and SD-5 and for discussion of the conceptual model, SD-5 will be combined with runoff from cranberry bogs because of the similar stressors, response pathways and resulting ecological effects. Areas of concern FTA-2 and LF-2 occupy 20 acres of land used for fire-training exercises that were conducted on the top of a former industrial/municipal landfill. Compounds disposed of in the landfill or burned on the fire-training area consist of fuel, waste oils, waste petroleum distillate solvents and domestic refuse. The PSFA is an active facility that is involved in the delivery of various types of fuel and was the site of a 2,000 gallon fuel spill in the 1960s (ABB, 1991).

The contaminants from these plumes would affect the northern boundaries of the ponds. Primary ground water contaminants of concern within SERGOU include chlorinated solvents and volatile organic compounds such as methanol (Table E-5). Preliminary studies, however, indicated that levels of volatile and semivolatile organics in surface water and sediments at these locations in the ponds were not elevated compared to other sites in the ponds in 1993. Further, it appeared that some of the detected compounds were introduced as contaminants during laboratory processing of the samples, e.g., di-n-butylphthalate and bis(2-ethylhexyl)phthalate detected in Ashumet Pond in April 1993; methylene chloride, zinc, and chloroform detected in Johns Pond in April 1993). The greater number of samples collected in August 1993 in Ashumet and Johns Ponds did not greatly increase the number of contaminants detected in the surface water. Neither trichloroethylene nor its metabolite, tetrachloroethylene, nor the common fuel constitutents of the plumes (e.g., benzene, toluene, and xylene), were detected in fish tissue or freshwater mussel tissue collected from the pond (HAZWRAP, 1995). The Quashnet River and Waquoit Bay are potential future sites for MMR ground water discharge effects in the absence of remediation and therefore the contaminants in the plumes pose a threat to estuarine receptors.

Little data are available on the quantities and effects of pesticides, polynuclear aromatic hydrocarbons, polychlorinated compounds, and heavy metals suspected of being present in the water, sediments, and biota in the ponds, rivers and streams, wetlands, and estuary. The water released from the cranberry bogs has contained pesticides and other contaminants that are toxic to trout and other fish species and the macroinvertebrates on which they feed (MBL Science, 1985). Pesticides from the MMR SD-5 area are primarily insecticides, rodenticides, and herbicides. Pesticides within the water column can bioconcentrate in aquatic organisms and accumulate in sediments, bioaccumulate in fish, mussel, or other invertebrate tissues and affect terrestrial wildlife that prey on these organisms, such as racoons and osprey. Concentrations of PCBs and the chlorinated pesticides DDD and DDE were higher in fish from Ashumet Pond than those from Johns Pond, but all pesticide residues were within the range for comparable reference sites (HAZWRAP, 1995). Analyses of fish enzymes and freshwater mussel lipids did not indicate exposure to high concentrations of chemicals; catfish from both ponds exhibited a high incidence of papillomas on their jaws and around their mouths and adenocarcinomas were found in the livers of two catfish from Johns Pond (Table E-7). The causes of these lesions could be contaminants, viruses, and/or genetic factors (Harshbarger and Clark, 1990; Baumann, 1992). Heavy rainfall can result in short-term increases and transport of elevated concentrations of chemical contaminants. These types of episodic events could cause lethal effects to biota.

Another toxic of concern in the watershed is the bioaccumulative and neurotoxic metal mercury. A concentration of 1.2 mg/kg was detected in one largemouth bass fillet during a study of the chemical contaminants in Ashumet and Johns Ponds (HAZWRAP, 1995). This concentration exceeded the U.S. Food and Drug Administration action limit of 1.0 mg/kg to protect human health. Deposition of mercury into surface waters and accumulation in sediments might produce sublethal effects in pelagic and benthic aquatic organisms, as well as piscivorous wildlife.

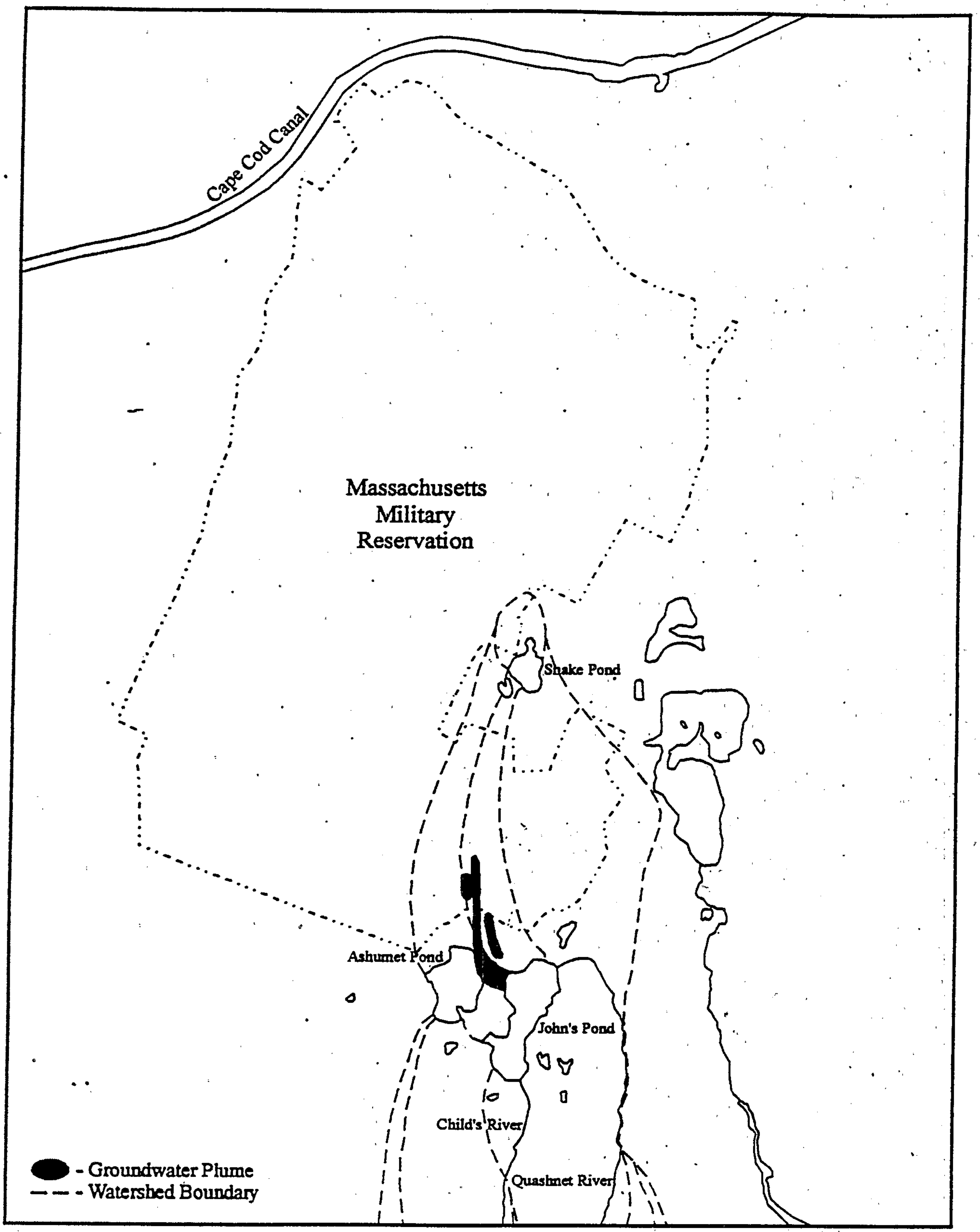


Figure E-7. Groundwater plumes in the Waquoit Bay watershed.

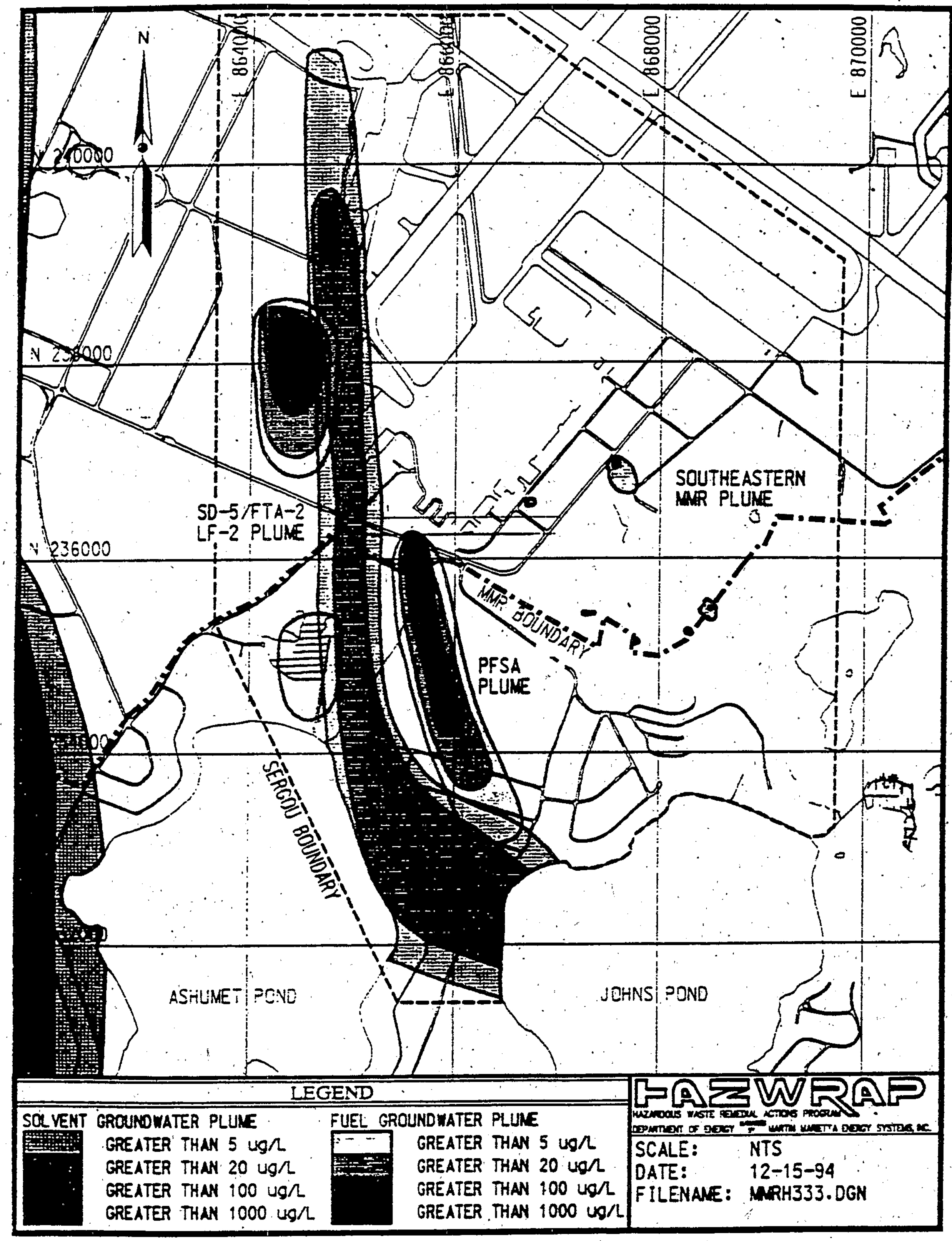


Figure E-8. Groundwater plumes as in Figure E-8, showing the plumes from the SERGOU in the vicinity of Ashumet and Johns Ponds (HAZWRAP, 1995).

Table E-5-1. Chemical contaminants in ground water from the Massachusetts Military Reservation. Data from Monitoring Well Fence 4, Figures 7.1 through 7.6, Volume II, HAZWRAP (1995). ND = Not detected.

	Wells				
	MW-528	MW-522	MW-519	MW-518	MW-523
VOC (μg/L)	ND			ND	
Tetrachloroethene		3	1-2		0.7
cis-1,2-Dichloroethene			8		
1,2-Dichloroethane			0.6		
Trichloroethane			16		0.3
Chloroform					3
Total Xylenes					2-43
Benzene					2
Ethylbenzene					11
1,2-Dichloroethene (total)					0.3
SVOC (μg/L)	ND	ND			
Di-n-butylphthalate			1	1	
Naphthalene					5
2-Methylnaphthalene					11
TPH (μg/L)	ND	ND	0.6	0.6	ND
Dissolved inorganics[1] (μg/L)					
Ca	11200		33000		
As				11	7.9-19.8
Fe				7050	1050-28,200
Mn				1250	400
Total inorganics[1] (μg/L)					
Cu	46				
K		1630-2230			
Fe			178-788	75.4-8600	7560-27,200
As				13	5.4-19.8
Mn				1450	214-380
Cd					3.3
Pb					3.4

Table E-5-1. Chemical contaminants in ground water from the Massachusetts Military Reservation. Data from Monitoring Well Fence 4, Figures 7.1 through 7.6, Volume II, HAZWRAP (1995). ND = Not detected (continued).

	Wells				
	MW-528	MW-522	MW-519	MW-518	MW-523
Mg					5630
Nutrients (μg/L)					
SRP[2]	26.23-26.39	4.19-22.64	23.62-43.21	6.15-21.33	
TSP[2]	25.07-29.87	6.13-1387	21.07-35.73	8.8-19.73	
NH_4[3]	0.19-0.63	0.14-0.68	0.09-0.10	0.05-19.81	
NO_3[3]	572.1-1397	396-1615	1931-2085	2.82-2014	

[1] Values exceeding background levels
[2] As P
[3] As N

Table E-5-2. Monitoring Well Fence 2 (Figures 7.7 through 7.12, Volume II, HAZWRAP, 1995).

	Wells			
	MW-540	MW-539	MW-543	MW-544
VOC (μg/L)				
Chloroform	2			1
Trichloroethene	0.8			3
Methylene Chloride	2			
Tetrachloroethene		2	0.6	
Trichloroethene			0.9	
SVOC (μg/L)	ND	ND	ND	ND
TPH (μg/L)	ND	ND	ND	0.7-0.9
Dissolved inorganics[1] (μg/L)				
Fe	72.6			103
Mn	500			
K		1680		
Mg		4830		
Al				606
Total inorganics[1] (μg/L)				
Fe	145			315

Table E-5-2. Monitoring Well Fence 3 (Figures 7.13 through 7.18, Volume II, HAZWRAP, 1995) (continued).	MW-540	MW-539	MW-543	MW-544
Mn	456			
K	1910	1600		
Pb		5.2-5.8		
Zn		105		
Al			802	
Nutrients (μg/L)				
SRP[2]	5.17-25.58	3.05-23.29	8.76	1.25-28.19
TSP[2]	8.27-26.67	6.67-23.47	10.67	5.07-31.2
NH_4[3]	0.41-6.68	0.25-1.96	1.55	0.36-39.26
NO_3[3]	40.64-3521	1551-3260	1032	14.74-1977

[1] Values exceeding background levels
[2] As P
[3] As N

Table E-5-3. Monitoring Well Fence 5 (Figures 7.13 through 7.18, Volume II, HAZWRAP, 1995).

	Wells				
	MW-525	MW-541	MW-521	MW-526	MW-524
VOC (μg/L)			ND		
Trichloroethene	11			25	10-59
Chloroform		0.7		0.5	
1,2-Dichloroethane					0.5
SVOC (μg/L)		ND	ND		ND
Di-n-butyphthate	1			2	
TPH (μg/L)	0.4-0.6	ND	0.4	0.4-0.6	0.3
Dissolved (μg/L) inorganics					
K	1640			2310	1770-3040
Fe		605		276	
Mn		413			
Ca		18300			28,500-39,500
Ba				72	
As				4.2	

Table E-5-3. Monitoring Well Fence 5 (Figures 7.13 through 7.18, Volume II, HAZWRAP, 1995) (continued)

	Wells				
	MW-525	MW-541	MW-521	MW-526	MW-524
Mg					5030-5740
Mn					250-443
Total inorganics[1] (μg/L)					
K	1600			2260	5480
Mn		368			254-597
Fe		90.7		137-514	158-14,500
Ca		16700			28,600-37,100
Ba				68.7	
As				6.5	8.4
Mg					4950-8260
Al					11000
Be					1.4
Cr					24.4
V					26.5
Nutrients					
SRP[2]	1.9-33.58	2.88-35.37	51.37-71.29	2.56-15.62	24.44-73.90
TSP[2]	18.67-35.47	0.05-33.6	48.27-60.27	9.87-20	29.33-65.87
NH_4[3]	0.83-2.59	0.94-51.15	0.32-0.69	2.027-15.09	0.04-24.78
NO_3[3]	158.8-1939	240.7-1404	13.25-111.6	662-4248	889.4-1622

[1] Values exceeding background levels
[2] As P
[3] As N

Table E-6-1. Chemical contaminants in Ashumet and Johns Ponds (Volume II, HAZWRAP, 1995, Figures 7-33).

Ashumet Pond April 1993				
	APSW-1	APSW-2	APSW-3	APSW-4
Water concentrations in $\mu g/l$				
VOCs	ND	ND	ND	ND
SVOCs			ND	
Di-n-butylphthalate	1	1		
Butylbenzylphthalate				1
PEST/PCBs	ND	ND	ND	ND
Metals				
Mn	34	35.7	34.6	29.9
NA	8660	8780	8630	8860
Ashumet Pond August 1993[1]				
	APSW-1	APSW-2	APSW-3	APSW-4
Water concentrations in $\mu g/l$				
VOCs	ND	ND	ND	ND
Acetone		16		
SVOCs		ND	ND	ND
Pentachlorophenol	1			
PEST/PCBs	ND	ND	ND	ND
Metals				
Ba	2.9-2.1	2.8-4.3	3	2.6
Ca	1920-2900	1930-2540	1885	1850
Fe	60.5-1250	44		
Pb	2.5			
Mg	2170-2230	2130-2170	2195	2200
Mn	29.6-1770	36.3-344	45.1	46
K	1170-2060	1170-1230	1270	1256
Na	8560-8920	8370-8770	9025	8767
Zn	5.7-12.1	6.1		

[1]Vol. II, HAZWRAP, Fig. 7-34.

Table E-6-2. Ashumet Pond sediments, 3rd quarter results. (Volume II, HAZWRAP, 1995, Table 7-4).

Ashumet Pond Sediments August 1993	**APSD-1**	**APSD-2**	**APSD-3**	**APSD-4**	**APCB-1**	**APCB-2**
Compounds						
VOCs ($\mu g/kg$)			ND		ND	
Tetra-chloroethane		1J				
1,1,2,2, Tetra-chloroethane						
1,1,1, Trichloro-ethane				2J		
Toluene	7			2J		95000J/59000
Chlorobenzene				2J		
Acetone	280J					16000J/100000J
2-Butanone (MEK)	20J					920J/1400J
Methylene Chloride	100					15000/22000
Carbon Disulfide	22					
Ethylbenzene						870/ND
SVOCs ($\mu g/kg$)						
Di-n-butylphthalate	220J	88J/ND	54		74J	
Bis-2-ethylhexylphthalate	170			820	49J	860
Di-ethylphthalate				51J		57J
TIC (Benzoic Acid)	570J	51J/75	160J	310J		
Pentachloro-phenol				53J		76J
Phenanthrene				270J		290J
Carbozole				55J		
Fluoranthene				390		400
Pyrene				380		470
Benzo(b)fluoranthene				170J		170J
Benzo(a)pyrene				150J		150J
Indeno(1,2,3cd)Pyrene				110J		
Benzo(g,h)perylene				88J		

Table E-6-2. Ashumet Pond sediments, 3rd quarter results. (Volume II, HAZWRAP, 1995, Table 7-4) (continued).

	Ashumet Pond Sediments August 1993					
	APSD-1	APSD-2	APSD-3	APSD-4	APCB-1	APCB-2
Pesticide/PCBs (μg/kg)	ND	ND	ND	ND	ND	-
4,4'-DDT						8.6
Metals (mg/kg)						
Al	1610	914/793	1110	548	397	1680
As	2.2					1.1
Ba	13	9.5/8.2	9.5	7.9	1.8	13.9
Ca	333	266/198	118	128	67.4	1170
Cu			2.3			12
Cr			2.3			7.4
Fe	1660	1250/1172	1860	592	732	4850
Pb	19.4J	12.8/8.7	2.7J	6J		22.4J
Mg	321	213/223	258	109	139	773
Mn	66	72.8/68	176	56.9	57	58.2
K	223	115/76	174	69.4	43.5	369
Na	129	56.3/73	43.8	60.7	45.5	85.5
V		3.6/3.0	4.5			12.9
Zn	43.7	15.4/19	10.2	12.4		
VOCs - Volatile Organic Compounds						
SVOCs - Semivolatile Organic Compounds						
PCBs - Polychlorinated Biphenyls				ND - Non Detect		
TIC - Tentatively Identified Compound				J - Estimated Value		

Table E-6-3. Chemical contaminants in Ashumet and Johns Ponds (Volume II, HAZWRAP, 1995, Figure 7-36).

Johns Pond April 1993	JPSW-1	JPSW-2	JPSW-3	JPSW-4
Water concentrations in $\mu g/l$				
VOC	ND	ND	ND	
Methylene chloride		9		
Carbon disulfide				0.5
SVOCs	ND			ND
Di-n-butylphthalate		2	2	
bis(2-chloroethyl) ether			2	
Diethylphalate			2	
PEST/PCBs	ND	ND	ND	ND
Metals				
Fe	48.9	73.3	48.9	
Mn	15.2	22.4	13.5	14.1
Na	8910	8780	8810	8840
Zn	4.3	5.5	4.8	4.3
Johns Pond August 1993	**JPSW-1**	**JPSW-2**	**JPSW-3**	**JPSW-4**
Water concentrations in $\mu g/l$				
VOCs	ND	ND	ND	ND
SVOCs		ND	ND	ND
Tributyl phosphate	16			
PEST/PCBs	ND	ND	ND	ND
Metals				
Al				20.1
As				2.1
Ba	6.9-24.7	6.7-8	6.9-11.5	7
Ca	2840-3350	2840-3270	2770-2800	2874
Fe	54.6-1240		24.5-159	
Mg	2130-2160	2150-2160	2150-2200	2148
Mn	36.5-1320	25.6	29.2-631	14.75
K	951-1100	969-998	995-1100	955
Na	8300-8630	8440-8800	8410-8880	8924
Zn	38.9			

Table E-6-4. Johns Pond sediments 3rd quarter results. (Volume II, HAZWRAP, 1995, Table 7-5).

	Johns Pond Sediments, August 1993					
	JPSD-1	JPSD-2	JPSD-3	JPSD-4	JPCB-1	JPCB-2
Compounds						
VOCs (µg/kg)NDND					ND/ND	
2-Butanone (MEK)	25J		11J			
Toluene	5					
Acetone	490J	3J	470J	7J		38J
Carbon Disulfide	5J		31J			44
Methylene Chloride	130		110			
SVOCs (µg/kg)		ND				
Di-n-butylphthalate	160J		130J	50J	62J/46J	60J
Bis-2-			130J	52J	45J/ND	
TIC (Benzoic Acid)						54J
PESTICIDE/PCBS	ND	ND	ND	ND	ND	ND
METALS mg/kg						
Al	5630J	741J	7050J	1630J	409J/-347J	2070J
As			1.9J			0.46J
Ba	32.9	3.8	40.1	7.7	2.2/1.4	10.3
Ca	925	167	1120	182	44.8/-64.3	328
Cu			7.1	17.3		3.8
Cr	10.1		10.9			2.5
Fe	3850J	1270J	5640J	1540J	671J/530J	1280J
Pb	24.2	5.2	26.6	3.9	ND/0.46	7.5
Mg	989	318	1250	355	162/127	192
Mn	147	17.2	126	64.2	11.4/7.1	30.2
K	520	112	599	142	147/39.8	104
Na	315	47.1	192	59.7	59.9/37.4	84.6
V	11.3	3.3	15.9	5.5		3.9
Z	34	9.4	39	11.1	7.0/4.1	21.1

Key:

VOCs - Volatile Organic Compounds

SVOCs - Semivolatile Organic Compounds

PCBs - Ploychlorinated Biphenyls

TIC - Tentatively Identified Compound

ND - Non Detect

J - Estimated Value

Table E-7. Summary of histopathological examinations for brown bullhead catfish from Ashumet and Johns Ponds, Cape Cod, MA (Volume II, HAZWRAP, 1995, Table 7.17)

Pathology	Ashumet Pond (frequency of occurrence)	Johns Pond (frequency of occurrence)
Exterior Sores/Growths	47%	67%
Liver Cancer	0.00	2 individuals
Macrophage Aggregates	80% moderate/severe	90% moderate/severe
Functional Liver Tissue	81%	0.81

Eelgrass Disease. Pathogens include infectious agents of disease such as viruses, bacteria, fungi, and protozoa. Disease is any impairment of the vital functions of an organism; it can be caused by other organisms known as pathogens (biological stressors) or by abiotic factors (physical and chemical stressors discussed above). Pathogens can be endemic or introduced. The severity of a disease is influenced by the susceptibility of the host, virulence of the pathogen, and environmental factors that can affect the ability of the host to resist infection as well as the proliferation of the pathogen in the environment or in the host. Diseases caused by pathogens affect commercially important finfish and shellfish species in freshwater and estuarine ecosystems, as well as the organisms on which they depend for food, shelter, and other resources (Sindermann, 1990; Couch and Fournie, 1993). Outbreaks of disease can occur sporadically, although chronic infections can produce sublethal adverse effects in some individuals of a population at all times. Biotic diseases can also affect behavior, development, growth, reproduction, or survival of the population infected by a particular pathogen, as well as indirectly affecting dependent populations and producing a cascade of effects in an ecosystem.

Although some pathogen-induced diseases of finfishes, shellfishes, and other aquatic organisms have been reported elsewhere in the Northeast and probably occur in Waquoit Bay watershed and black-crowned night-herons that feed in the bay have been found with abdominal lesions of unknown origin (WBNERR, 1993), the most significant biological stressor recognized in the watershed is a disease affecting eelgrass. Eelgrass was at one time the dominant submerged aquatic vegetation in coastal areas of the North Atlantic. In the 1930s the wasting disease, caused by a slime mold (*Labyrinthula*) eradicated about 90 percent of the eelgrass meadows on both sides of the Atlantic. The eelgrass recovered, but then declined again. In the 1980s, another outbreak of the disease affected eelgrass beds in the United States (Short et al., 1988). After the 1930s outbreak, many species characteristic of the eelgrass meadows disappeared, including the gastropod snails *Bittium alternatun* and *Miterella*, the Atlantic brant (*Branta bernical hrota*), and the bay scallop (Short et al., 1988; Short et al., 1992). Bay scallop larvae and juveniles attach to eelgrass blades to effectively avoid predators (Pohle et al., 1991).

The eelgrass wasting disease has been found in a 1989 survey only in the Hamblin Pond area of the Waquoit Bay complex (Short et al., 1992). The marine slime mold is adapted to the more saline waters of the lower reaches of coastal ponds. In the aftermath of the wasting disease, some eelgrass survived in the less saline parts of estuaries. Today, these eelgrass beds are threatened by their proximity to the coasts with their collateral load of nitrogen and suspended sediments (Short, 1988). The wasting disease might also act synergistically with stress from reduced light resulting in decreased eelgrass growth.

Fisheries Harvesting. Harvesting of finfish and shellfish species by humans is another biological stressor identified in the Waquoit Bay watershed. Removal of aquatic resources at rates faster than the organisms can reproduce and replenish the populations results in reduced abundances and limitations in distribution, as well as adverse effects on the species that prey on these commercially- or recreationally-important species. Overharvesting has been recognized as serious threat to the stability of freshwater, estuarine, and marine ecosystems (reviewed in Gulland, 1983). Commercial fisheries can deplete stocks year-round, although fishing pressure is greatest in summer when weather conditions are best.

In the Waquoit Bay watershed, most of the finfish harvesting effort occurs offshore, focusing on winter flounder, summer flounder, tautogs, and Atlantic pollack. Adult winter flounder can be restricted in their offshore distribution range from certain estuaries, so that it is not clear that the Southern New England (SNE) stock is indeed a distinct subpopulation of fish (biological stock as opposed to economic stock). The same situation might apply to adult tautogs. Summer flounder are at the northern extension of their range in the SNE area, so that this species has a lesser impact in the offshore region from Waquoit Bay. Quantitative assessments provide evidence of regional impacts resulting from fishing mortality and natural mortality (resulting from habitat degradation, pollution effects, eutrophication, meteorological events, and long-term changes in climate).

Winter flounder and summer flounder are part-time estuarine residents that are important commercial species in southern New England. Fishing mortality resulted in a 55 percent decrease in annual survival for summer flounder and a 38 to 42 percent decrease for winter flounder in 1992 (NMFS/NEFSC/CUD, 1992). As a consequence of combined fishing and natural mortality, the annual survival for summer flounder is 27 percent and that for winter flounder is 24 to 28 percent, which implies that both species suffer from excess harvesting. Thus, regional commercial and recreational fishing activities play an important role in their distribution and abundance in Waquoit Bay. The SNE stock biomass levels for summer flounder decreased dramatically from 1985 to 1991, and was dominated in 1991 by fish aged two years and younger (adults are viewed as two and older). The winter flounder stock in SNE decreased to record low levels between 1989-1991, with a 1991 commercial catch of 4700 metric tons and a recreational catch of 1100 metric tons (NMFS/NEFSC/CUD, 1992).

For the tautog, in Southern New England state waters the maximum estimated fishing mortality ranges from 0.15 to 0.33 (14 to 28 percent decrease in annual survival). The Massachusetts state bottom trawl survey for Region 1 (Buzzards Bay and Vineyard Sound) and Region 2 (Nantucket Sound) has shown a decreased index of abundance from 1982-1986 through 1992, even though a common indicator of overfishing, reduction in the average size of the adult tautog caught in Region 1, has not been detected (Caruso, 1993).

Recreational fishing of rainbow trout, brook trout, yellow perch and smallmouth bass within the freshwater ponds systems is creating a demand on these resources and an increase in local fishing efforts could reduce these resident finfish populations.

Shellfishing (commercial and recreational) in Waquoit Bay is regulated by the shellfish wardens in Falmouth and Mashpee; commercial harvest records extend back to 1965 in Falmouth, and from 1976 through 1987 in Mashpee (Table E-8). Town shellfish landings depend on shellfish seed set or availability and fishing effort related inversely to shoreside employment opportunities (MacKenzie, 1989). The quahog landings have been relatively stable during this period. Softshell landings increased, probably as a consequence of more effort directed toward this shellfishery. Scallop landings, however, have been mixed due to the short-lived (two years) nature of this species and variable recruitment. Adult quahogs are susceptible to overfishing because of their slow growth and variable recruitment; the population in the bay is dominated by commercially undersized clams (Funderburk et al., 1991). The slow growth rates might also contribute to increased susceptibility to predation. It takes approximately two years for juvenile quahogs to reach a minimum length of two inches in southern Massachusetts.

Table E-8. Shellfish Harvest by Year in Waquoit Bay, From Falmouth Commercial Harvest Records.

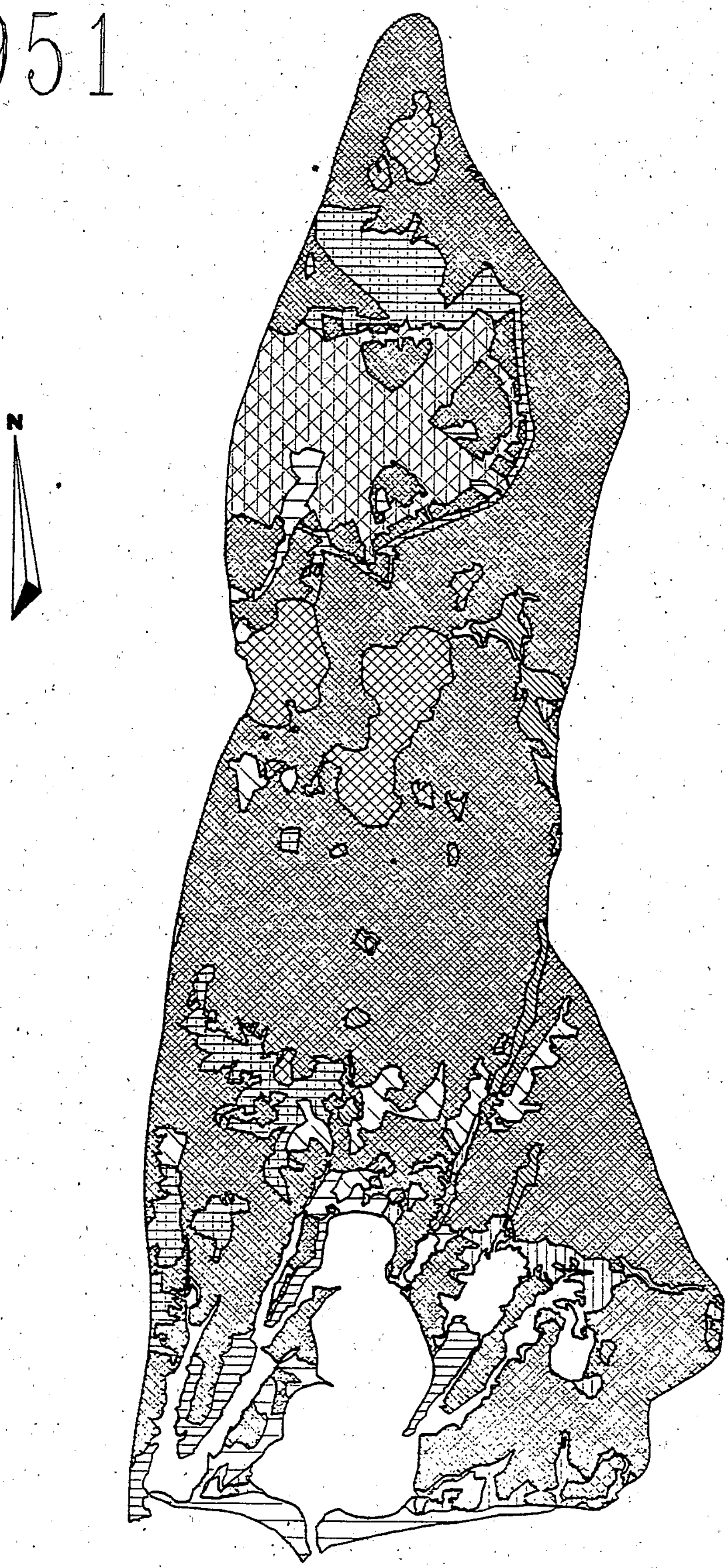
Year	Quahogs	Bay Scallops	Soft Shell Clams	Oysters
1976	3274	2074	201	–
1977	3930	570	232	–
1978	3292	41477	300	–
1979	3590	7200	950	54
1980	3985	244	1625	654
1981	3540	596	1730	–
1982	4650	985	1680	65
1983	4410	550	1938	100
1986	2750	3150	1275	15
1987	3045	2600	1819	–

APPENDIX F: LAND USE MAPS FOR WAQUOIT BAY WATERSHED

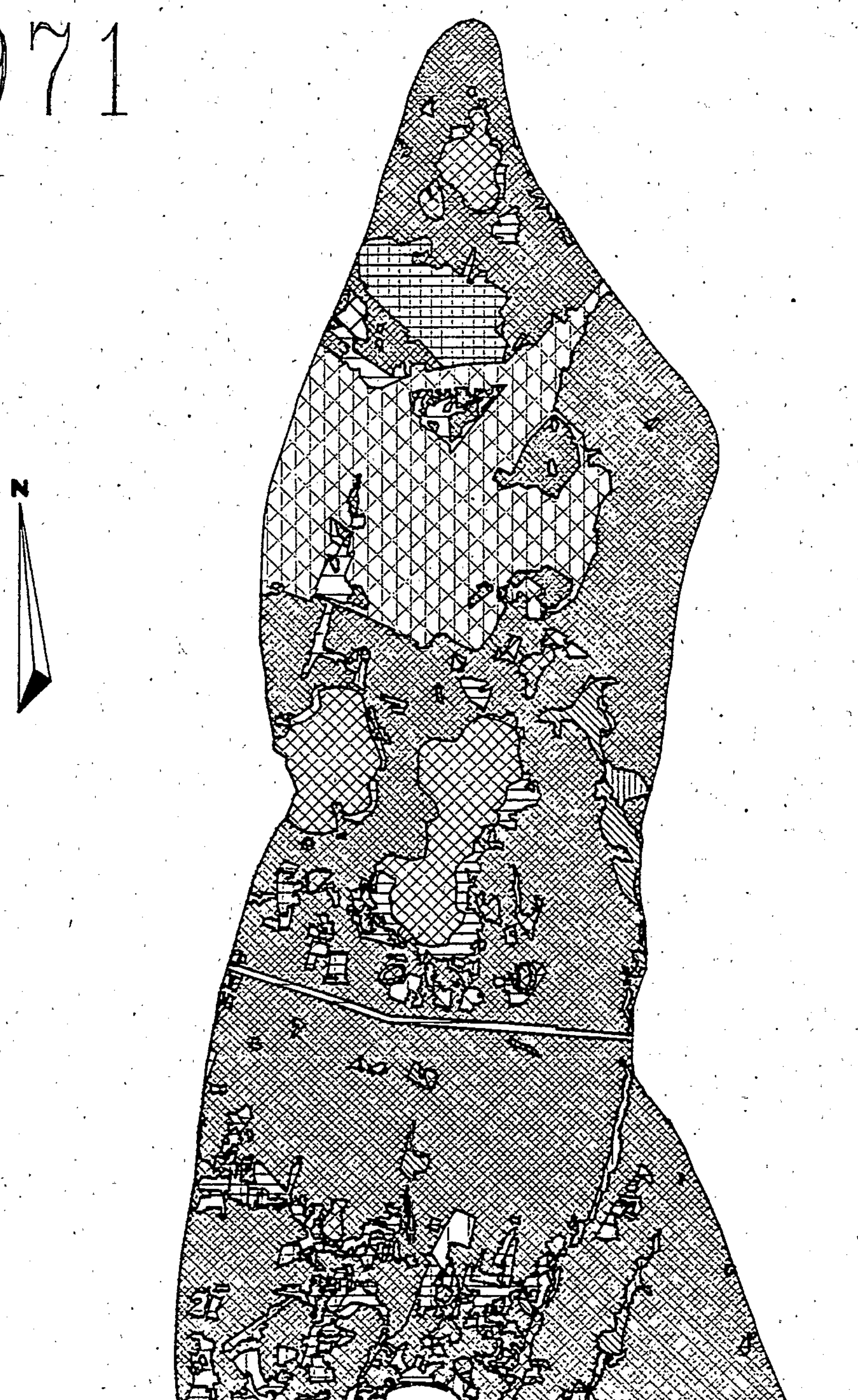
Land Use Categories by Classification System

1951	1971	1980	1985/1990
40 Forest Types	Tilled/Tillable	Agricultural	Agricultural
Agricultural	Unused Tillable	Pasture	Pasture
Agricultural with Walls, Forest, and Wetland	Pasture	Forest	Forest
Agricultural with Fresh Water Meadow	Orchard	Open Space	Fresh Water Wetland
Abandoned Field	Abandoned Field	Urban	Mining
Abandoned Orchard	Abandoned Orchard	Water	Open Space
Orchard	Cranberry Bog	Cranberry Bog	Participation Recreation
Cranberry Bog	Nurseries	Other	Spectator Recreation
Urban	Heath		Water Based Recreation
Fresh Water Meadow	Sand		Multi-Family Residential
Deep Fresh Water Marsh	Power Lines		High Density Residential
Shallow Fresh Water Marsh	40 Forest		Medium Density Residential
Shrub Swamp	Dump		Low Density Residential
Salt Marsh	Automobile Dumps		Salt Water Wetlands
Fresh Open Water	Filter Bed		Commercial
Salt Open Water	Mining - Sand and Gravel		Industrial
Sand	Mining - Other		Urban, Open & Public
	Water		Urban Transportation
	7 Fresh Water Wetlands		Waste Disposal
	3 Salt Water Wetlands		Water
	4 Water Based Recreation		Woody Perennial
	5 Participation Recreation		Cranberry Bog
	5 Spectator Recreation		Golf Course
	1 Environmental Recreation		Marina
	2 Urban Industrial		Ocean
	3 Urban Commercial		
	10 Urban Residential		
	5 Urban Transportation		
	2 Urban Open and Public		

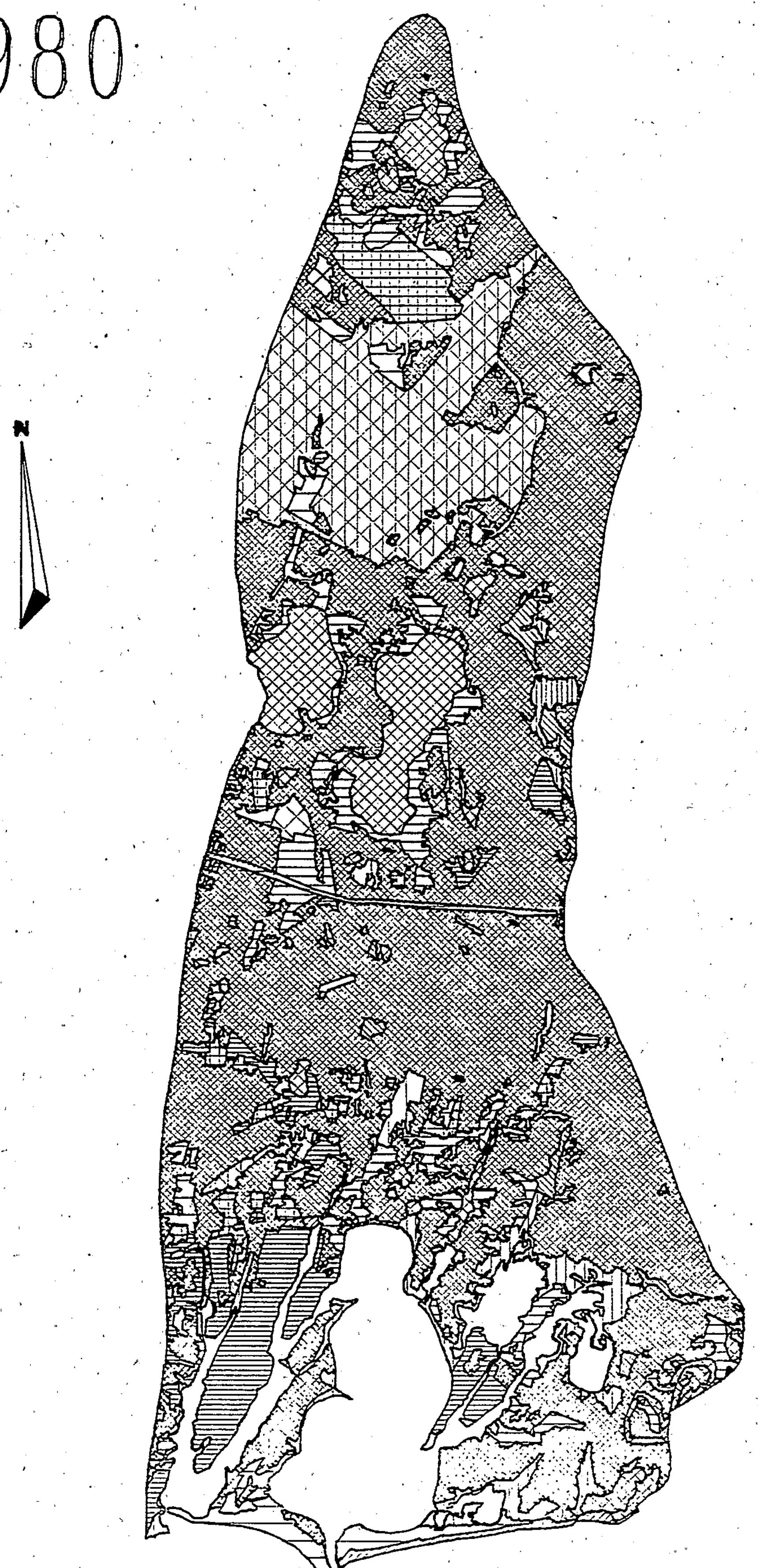
1951



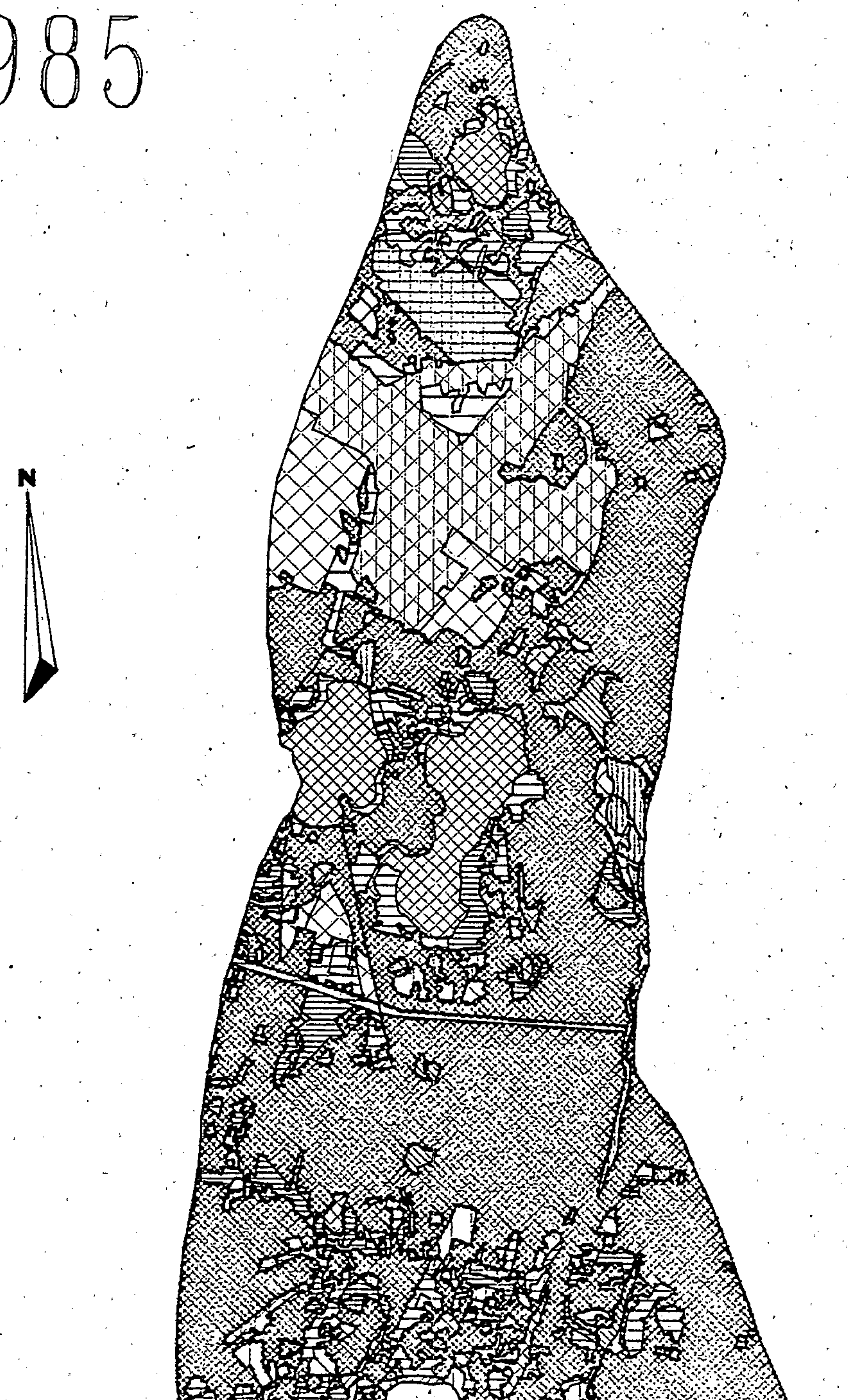
1971



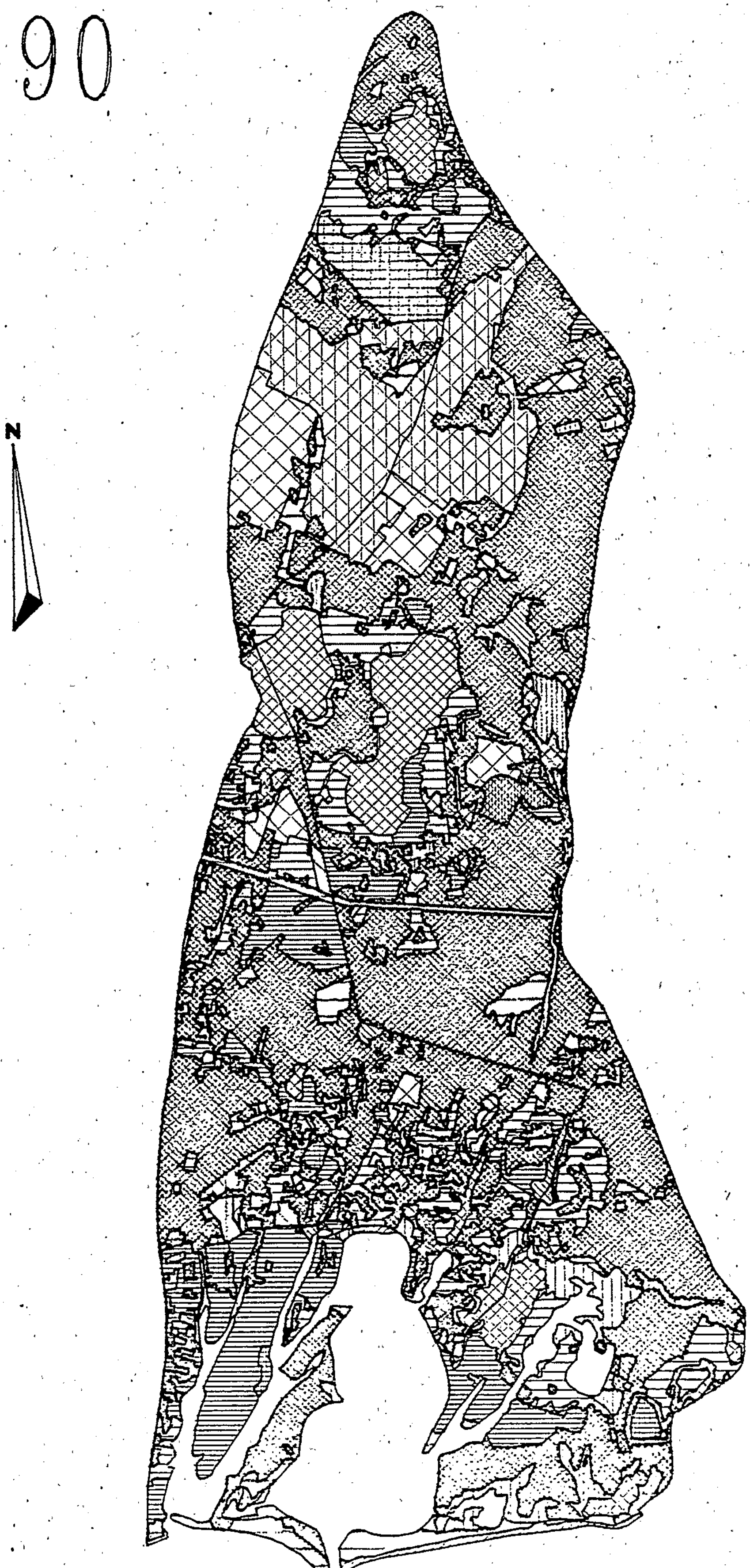
1980



1985



1990

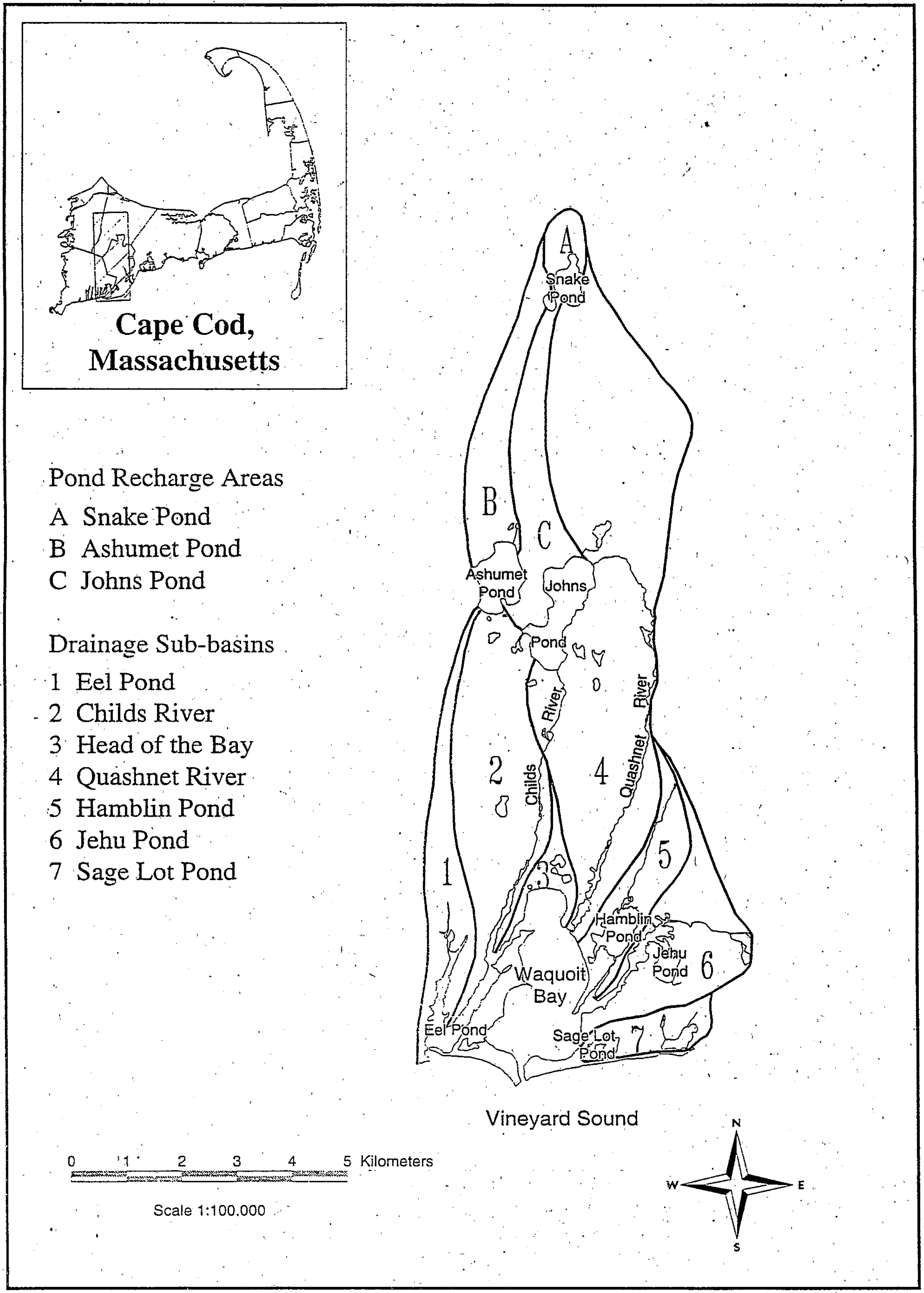


Land Use Categories

- Crop Land
- Pasture
- Forestland
- Fresh Water Wetland
- Mining
- Open Land
- Participation Recreation
- Spectator Recreation
- Water Based Recreation
- Multi-Family Residential
- High Density Residential
- Medium Density Residential
- Low Density Residential
- Salt Wetland
- Commercial
- Industrial
- Urban, Open and Public
- Transportation
- Waste Disposal
- Water
- Woody Perennial
- Cranberry Bog
- Golf Course
- Marina

Land Use Change over Time (ha)

Land Use	1951	1971	1980	1985	1990
Agricultural Land	358.38	175.33	162.07	117.27	114.18
Pasture	140.53	28.86	12.89	28.62	36.96
Forest	3717.88	3421.26	3201.53	3059.65	2649.91
Fresh Water Wetlands	31.19	74.80	49.56	80.87	83.05
Mining		20.09	18.79	23.50	27.89
Open Lands	185.97	177.94	191.77	171.26	179.52
Outdoor Recreation--Participation				6.38	5.15
Outdoor Recreation--Spectator		0.65	0.22	3.18	3.18
Outdoor Recreation--Water Based		39.70	27.14	29.43	28.05
Multi-Family Residential		1.52		10.55	29.64
Dense Residential				34.26	43.83
Medium Residential		122.23	286.19	343.30	480.40
Light Residential	90.76	261.83	371.56	398.36	574.77
Salt Water Wetlands	110.21	118.55	143.06	129.47	129.10
Commercial		4.87	1.46	11.84	17.22
Industrial		2.54		1.96	3.73
Open and Public Urban Land		17.94	12.58	203.03	224.34
Urban Transportation	425.64	580.43	591.98	437.01	440.40
Waste Disposal		0.92		2.42	4.07
Open Water	321.71	324.42	324.34	354.48	371.67
Woody Perennials		25.30	21.58	34.18	14.83
Cranberry Bog	111.11	68.91	51.63	31.71	41.77
Golf Course		24.92	25.18	26.85	46.21
Marina		0.53			2.78
Total	5493.39	5493.01	5493.53	5539.58	5549.86
Total minus open water	5171.68	5168.59	5169.19	5185.10	5178.19


Cape Cod, Massachusetts
Pond Recharge Areas
A Snake Pond
B Ashumet Pond
C Johns Pond
Drainage Sub-basins
1 Eel Pond
2 Childs River
3 Head of the Bay
4 Quashnet River
5 Hamblin Pond
6 Jehu Pond
7 Sage Lot Pond
A
Snake Pond
B
C
Ashumet Pond
Johns Pond
Childs River
Quashnet River
2
4
1
3
5
Hamblin Pond
Jehu Pond
6
Waquoit Bay
Eel Pond
Sage Lot Pond
7
Vineyard Sound
0 1 2 3 4 5 Kilometers
Scale 1:100,000
N
W
E
S